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CEREAL CHEMISTRY

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CEREAL CHEMISTRY OF TODAY

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Modern cereal chemistry is one of the important branches on the biochemistry tree, and in recent years it has been enjoying a vigorous growth. There is no reason for believing that this growth is likely to be in any way restricted, or that the time will ever come when cereals and cereal products will cease to be among the most important of our foodstuffs. It is not difficult to discover causes for the recent expansion and organization of activities in the field of cereal chemistry, and in the first issue of a new journal devoted to this field of activity there may properly be included a brief discussion of cereal chemistry in general, and of the interests and aims of the American Association of Cereal Chemists, the organization by which this journal is sponsored. This discussion will be confined chiefly to cereal chemistry as related to the wheat and flour industry, with which by far the greater number of cereal chemists are concerned today. What is the present status of cereal chemistry? What has it accomplished? What has it failed to accomplish, and why? What may chemistry reasonably be expected to do for the wheat industry of the future?

The dependence of practically all modern industries on the services of chemistry is too well known to require more than the slightest mention. Chemistry evaluates the raw materials and standardizes the finished products with respect to grade and quality. Compared with most of the more important industries, however, the wheat industry has been rather slow to enlist the services of chemistry, and it is only within the last decade or two that chemistry has entered the service of the millers and bakers in the same capacity that it has for a much longer period been a positive necessity to the mining, steel, dye, sugar, and other large industries. Where ten years ago there were but few commercial cereal chemists in this country, there are at present probably in excess of five or six hundred.

There are reasons for the comparatively slow development of chemistry in relation to the wheat industry, as well as for the recent greatly increased activities in the field. A few of the more important ones may be briefly cited. The relatively slow development from the standpoint of commercial interest has been due to a combination of circumstances, chief among which is the fact that only in recent years has the necessity for strict standardization of wheat flour with respect to grade and quality assumed an importance the magnitude of which is all out of proportion to that of former times. The change from lack of standardization to standardization has been more abrupt in the wheat industry than in most others, owing in a large measure to excessive production of wheat products stimulated by the exigencies of the World War. Other causes contributing to this condition are those which are responsible for similar well recognized conditions existing in other industries, of which the automobile industry furnishes an excellent example. We need only to consider modern tendencies toward such things as the recent growth of cities at the expense of rural communities, competition resulting from centralization of resources in a few large industrial plants rather than in a large number of smaller ones, and greater preference for manufactured articles over home-made ones. Aside from economic and psychological considerations which make for stricter standardization of wheat products, the industry is becoming increasingly concerned with the problem of deterioration in wheat quality which always accompanies the depletion of soil fertility and the invasion of plant diseases and insect pests. These conditions, of course, result largely from lack of proper systems of crop rotation, failure to employ the most efficient methods of cultivation, etc., in our farming practice, and they are similar to those which have been experienced on the older agricultural soils of Europe. This clearly indicates that a more thoro knowledge of the principles of the chemistry of soil fertility in relation to wheat quality is as vital to the permanent welfare of the wheat industry as is cereal chemistry, itself, for the composition and quality of wheat depend very largely on soil and climatic conditions. Perhaps one of the most important handicaps to the development of cereal chemistry in its commercial aspects has been a decided lack of exact knowledge with regard to the chemical factors which are exclusively responsible for baking quality or "strength" in wheat flour. This is in spite of the enormous number of researches bearing on this point, which have been conducted over a long period of years, chiefly by chemists not in the employ of commercial interests. However, it must be borne in mind

that few industries use for their raw material substances which are as complex in their chemical composition, structure, and properties as is a kernel of wheat or the flour milled therefrom. Even the incomplete knowledge which we now possess has had to await recent developments of physical, and more especially colloid, chemistry. Progress has been slow, but very definite and highly satisfactory to those who in some measure understand the complexities involved in the chemistry of biological material, in which the chemist must deal with mixtures of proteins, salts, fats, enzymes, etc., nearly all of which are of the nature of emulsoid colloids.

To indulge in more than a brief general reference to the accomplishments of chemistry in relation to the wheat industry would be far beyond the scope and purposes of this paper. The published accounts of researches bearing directly or indirectly on all phases of the application of chemistry in the industry involve many thousands of separate papers and reports. Many of the most important of these researches have been done without special consideration of their subsequent commercial value, but solely with the object of increasing our knowledge of biochemical substances. Others have been planned strictly from the viewpoint of practical or industrial application. The result of these investigations has been the accumulation of chemical information on practically every phase of the handling of wheat and flour. Methods have been developed, and are still being perfected, by means of which most of the numerous constituents of the wheat kernel may be estimated with some degree of accuracy. In the flour mill the various mill streams have been found to possess individual chemical characteristics by which they may be readily identified. This affords chemical means for the accurate control of each milling process. The application of biochemical principles in the bakeshop is rapidly doing away with guess work in bread making. Many of the perplexing problems regarding yeast and yeast fermentation have been solved. A large volume of work has been done in devising methods and means of artificially bleaching flour, and this may now be done with various chemicals which may be used in such a manner that apparently no injury is done to the keeping quality of the flour, to its nutritive value, or to the health of the consumer. Chemistry has pointed out the conditions necessary for the successful storage of grain in large quantities, and it has indicated the causes and proper methods of elimination of dust explosions in mills and elevators. It has to some extent determined the nature of various kinds of wheat damage, such as rust, heat, and frost injury. Through the aid of chemistry much has been learned with respect to the influence of environmental factors, such as soil,

climate, etc., on yield, composition, and quality of wheat. Some important phases of the "yellow-berry" question have been satisfactorily dealt with by chemists. The number of minor difficulties which have been more or less successfully cleared up by chemistry is almost without limit. Among these may be mentioned control of insect pests, effect of insecticides on wheat and wheat products, "ropiness" in bread, staling of bread, the use of artificial flour and bread "improvers," and the employment of wheat substitutes in bread making.

Having called attention to some of the more conspicuous accomplishments of cereal chemistry, it is now necessary to consider briefly some highly important instances in which accomplishment has been lacking in certain respects, and in a manner which has seriously impeded industrial progress in certain directions. The most serious of these is, of course, the decided lack of exact chemical methods for the rapid and accurate estimation of strength or baking quality in wheats and flours. This arises chiefly from the incompleteness of our knowledge of all of the factors upon which strength fundamentally depends. Actual baking tests conducted by expert bakers under carefully controlled conditions must still be resorted to in order that flour strength may be accurately judged. There are at least three well known objections to the baking test: It requires several hours of valuable time, its success depends largely on the skill of the operator, and its results are difficult to express in exact figures of universal meaning. In defense of the chemists, however, it must be emphasized that failure along this line can not be traced to lack of application to the problems involved. A vast amount of effort and the best available chemical training and skill have been brought to bear on this matter, and the best that can be done is to report considerable progress. At present it appears to be beyond dispute that flour strength is not dependent on any single factor, but that it is the result of several factors. Cereal chemists have long realized that gluten quality is of equal importance with gluten quantity if not more important; but while quantity of gluten may be accurately estimated, precise chemical methods of measuring and expressing gluten quality have been decidedly non-existant. A method for the measurement of gluten quality which gives considerable promise has recently been suggested. This method depends on data obtainable from viscosity measurements of flour-and-water suspensions, and it is said to give a picture of the "colloidal properties" of flour. One of the two gluten proteins, i.e., glutenin, is found to be the constituent responsible for variations in colloidal properties and hence in gluten quality. It is now a widely accepted belief that flours may have good gluten quality as well as

quantity and yet be weak because of low diastatic value. With respect to the proper handling of dough, the need for regulating hydrogen-ion concentration during fermentation has recently been strongly indicated and emphasized, hence a knowledge of buffer values of flours has been found useful in predicting fermentation periods. Altho the principles underlying these recent advances will surely find application, it can scarcely be hoped that all the problems relating to flour strength will be solved through their use. Speaking from personal experience with Nebraska-wheats, the writer has encountered wide variations in baking quality for which repeated applications of all the principles just mentioned have offered no explanation. Perhaps proteolytic enzymes, or even some unknown enzymes or harmones, play a part at present unknown. At any rate it appears that the baking test is the only reliable quality test, and that if it is ever improved upon by the chemist, either its successor must be a test which will account for several factors at once, or it must consist of a group of short tests, each accounting for a single factor. The difficulties to be here encountered may be well appreciated when one considers that the most recently suggested method for the estimation of diastatic value alone, requires nearly as much time and attention as the baking test, itself. Information is also needed on matters such as the generally recognized inferiority of "new" wheat as compared with the same wheat after aging, and the exact nature of the processes involved in what is known as "sweating" in wheat. Why is it that gluten may be injured by close grinding? Does tempering produce any important biochemical changes, and if so, what are they? The surface has barely been scratched in such problems as the possible regulation of wheat quality by the proper use of artificial fertilizers. The application of principles of colloid chemistry to cereal problems is just beginning to be appreciated. In fact the whole field of cereal chemistry is inviting a more thoro cultivation, and past accomplishments provide bright hopes for the future.

In calling attention to the various weaknesses and shortcomings of modern cereal chemistry one especially important feature must not be overlooked, and it should also be noted that this feature is chiefly responsible for the present organization known as the American Association of Cereal Chemists. This is the well known lack of proper standardization of the analytical methods employed by cereal chemists, a condition which unfortunately exists even with respect to the most common daily routine methods. The annoyances, embarassments, and even financial losses which frequently occur as a result of this condition are quite familiar to all who are associated with the

wheat industry. However, no apologies should be necessary at this stage, at least to those who are sufficiently acquainted with the complications involved in the accurate estimation of even the commonest biochemical constituents such as moisture, ash, and protein. When, in the light of this knowledge, one considers also that the importance that cereal chemistry has assumed in relation to the industry is of comparatively recent date, the present condition of affairs is not at all surprising. Nevertheless, the situation is highly unsatisfactory, and altho relief in such matters is necessarily slow, it must be surely and carefully planned. In justice to cereal chemistry in general, these reasons for the present lack of standardization of methods should be in some way made known to those whose interests in the science are confined to practical results rather than to the means by which the results are obtained.

It was to meet the needs arising from the situation just outlined that, seven or eight years ago, a small, enthusiastic group of young cereal chemists, most of whom were located in the southwestern hard winter wheat area, organized the association under its present name. There was already in existence an association of non-commercial cereal technologists including chiefly experiment station and government workers. This was known as the American Society of Milling and Baking Technology, and its objects and aims have been similar to those of the American Association of Cereal Chemists. Recognizing that fundamentally both organizations had common interests for the most part, there has been, during the last year, an amalgamation of the two associations, retaining the name of the younger organization. As previously indicated, the American Association of Cereal Chemists has been organized chiefly for the purpose of perfecting, standardizing, and supplementing the analytical methods employed by cereal chemists. It has also undertaken to establish a suitable medium for the publication of worth-while researches in the field of cereal chemistry and closely allied subjects. Other benefits which science, industry, and individuals may derive from such an organization are numerous and obvious. The association now has approximately 250 members, and it appears to be permanently established on a solid foundation.

A VISCOSIMETRIC STUDY OF WHEAT STARCHES

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A review of the literature[1] on cereal chemistry as applied to milling and baking problems will show that nearly every constituent and property of flour has been studied and examined with more or less thoroness for its relationship to baking quality. It is interesting to note that the starch in flour has received the least consideration, even tho it constitutes the major portion of the flour. No systematic study of its relationship to baking quality is reported in the literature. Only three or four incidental observations have been made which suggest differences among wheat starches.

Whymper (1909), by a microscopic technic, showed that wheat starches differ in their resistance to diastatic action. He found that the degree of resistance varies with the quantity of gluten in a flour and suggests that the nature of the starch in flour may have a certain bearing on its strength.

Stakman (1918) and Leach (1919) suggest that differences which different strains of wheat exhibit in resistance to rust may be due in part to differences in the structure of their starches.

Collatz (1922), in studying the action of added diastatic ferments on flour, found that the starch of strong flours appeared to be more easily hydrolyzed by diastatic ferments than that of weaker flours.

In spite of these observations the assumption seems to prevail quite generally that wheat starches are identical. This assumption has constituted a fundamental basis for many important conclusions drawn from experimental results of investigations in cereal chemistry. A recent illustration is Rumsey's (1922) conclusion that diastatic activity of flour is indicated by the amount of maltose produced as a result of autolytic digestion. Obviously this conclusion rests on the assumption that wheat starches are identical in their resistance to diastatic action.

In view of these facts it seemed worth while to search for distinguishing properties of wheat starches, to measure them—if they exist—in quantitative values, expressive by numerical units, and to correlate these values with other properties of flour, baking quality

[1] Recent reviews are contained in Bulletins 8 and 9, American Institute of Baking.

especially.[2] An examination of wheat starches for such properties was the purpose of the investigation reported in this paper.

Starch

Because of its wide and abundant distribution and because of the important part which it plays in plant metabolism and every-day life in general, starch has been the subject of extensive research. In recent years this research has been further augmented by the increased industrial application of starch and its products. According to Sponsler (1922), fully five hundred investigators have worked with starch. The resulting literature is characterized by confusions in terminology and more or less contradictory conclusions. A review of this literature shows that very few facts have been definitely established regarding the physico-chemical properties of starch. Of these the only noteworthy ones are: that the per cent composition of starch is indicated by the formula $C_6 H_{10} O_5$, that glucose is its final hydrolysis product, and that there are differences among starches from different plants.

The researches of Meyer (1895), Nossian (1883), Samec and Haerdtl (1920), MacNider (1912), and others, show variations in starch structure. Observations of Meyer on sorghum starches and those of Collatz on wheat starches show such differences or variations among starches of the same species. That significant properties of starches may be ascertained quantitatively in numerical units by the viscosities of their pastes, is indicated by the experiments of Samec and Haerdtl, and of MacNider. Their observations point to interesting possibilities in the use of viscosimetric methods in the study of physico-chemical properties of starch. The experimental studies reported in this paper are exploitations of these possibilities in the study of wheat starches. The work has divided itself into two phases or parts. One of these is concerned with the phenomenon of gelatinization, and the other is an application of viscosimetric methods to a comparative study of wheat starches. Only the comparative studies are reported in this paper. The studies on gelatinization will be reported in another paper. Before entering upon a discussion of this experimental work, brief consideration will be given to the phenomenon of viscosity and methods for its determination.

[2] From the nature of the baking process it is apparent that starch plays a rôle of inert matter until after the starch grains have been denatured by oven heat. This probably occurs after the loaf has assumed its final shape as a result of coagulation of the flour proteins. For this reason it is improbable that there can be differences among starches sufficiently great to have any direct effect on baking quality. However, differences among them may be indicative of other factors or properties which do have a direct relation to baking quality. Moreover, it is not at all unlikely that the character of the starch gel may affect some of the properties of the finished loaf, especially the keeping quality.

Viscosity

A substance which will deform permanently to a degree directly proportional to the deforming force applied to it is said to be viscous. The term viscosity is used to denote the resistance due to internal friction which viscous substances offer to deforming forces. If a viscous substance fills the space between two parallel planes a distance S apart, then the tangential force F required to maintain a velocity V of one plane with respect to the other will cause a rate of shear equal to $\frac{V}{S}$ throughout the substance. Obviously the force F is equal to that caused by the internal friction of the substance. The ratio of this force to the rate of shear is called the coefficient of viscosity, usually expressed by the Greek letter eta, η. Hence $\eta = \frac{FS}{V}$

The unit for viscosity in the C. G. S. system is the tangential force acting on one of two parallel planes, each one centimeter square and one centimeter apart, so as to cause a velocity of one centimeter per second of the plane acted upon with respect to the other, the space being filled by the viscous substance. In honor of Poiseuille, Bingham has named this unit the "poise"; and its submultiple, which is one one-hundredth as large, the "centipoise."

For the sake of convenience, especially in technical work, it has been customary to determine specific viscosity rather than absolute viscosity. Specific viscosity expresses viscosity in the terms of some standard, which usually is the specific viscosity of water arbitrarily placed equal to unity. It so happens that the viscosity of water at 20° is 1.005 centipoises. As a result specific and absolute units of viscosity are identical within ordinary limits of accuracy.

The Viscosimeter

Of the numerous viscometers which are now in use, the Stormer seemed especially adapted to tracing the viscosity of starch suspensions through temperatures ranging from 25° to 95°, and was therefore selected for this work. This instrument was designed primarily for technical purposes and operates on the principle developed by Couette (1888). This principle consists in measuring the resistance which the viscous substance offers to the rotation of a cylinder immersed in it. In the case of the Stormer instrument the rotating force is gravitational. A falling weight acting through a simple system of gears rotates the cylinder. Viscosity is measured by the time required for the cylinder to make a certain number of revolutions, usually one hundred.

The viscous substance is contained in a cup which is set inside a larger cup. The latter can be used as a heating bath by filling the space between with water and placing a burner underneath. The operation of the instrument is so simple and rapid that 40 to 50 viscosity determinations can be made in from 15 to 20 minutes, the time required to raise the temperature of the outside bath from 20° to 100°.

Calibration of Viscosimeter

Higgins and Pitmann (1920) have shown that absolute viscosities can be determined by the Stormer viscosimeter. However, conversion of Stormer readings into their equivalent absolute units required calibration with suitable viscosity standards. Besides water, Bingham and Jackson (1917) recommended sucrose solutions and ethyl alcohol–water mixtures, the viscosities of which have been carefully determined. For the calibration of the instrument used in this investigation, sucrose solutions were selected. Bingham and Jackson (1917) have determined the absolute viscosities of water for every degree from 0 to 100 and of sucrose solutions of 20%, 40%, and 60% concentrations at every 5 degrees from 0 to 50 inclusive. These values were employed in the calibration of the Stormer viscosimeter. The sucrose used was furnished by the Bureau of Standards in a glass-stoppered bottle labeled as follows:

$20°C=78°$ .342
(a)
546.1 mu
$20°C=66°$ .529
(a)
589.25 mu
When C=26 gms. in 100 cc. water.
Heat of combustion=3949 calories per gm.

A 3-gram sample of this sucrose lost 0.0007 grams as a result of heating in an oven at 102°C. for 16 hours. The amount of moisture which this loss in weight might represent was not corrected for in preparing the above viscosity standards. Preliminary experiments with viscosities of starch pastes showed the necessity of determining viscosities over a wider range than would be possible by means of any one weight. The viscosimeter was therefore calibrated with two different weights of 100 and 150 grams, respectively. As the calibrating technic was identical with that of subsequent viscosity determinations of starch pastes, it will be worth while to describe it in some detail at this point. The viscosimeter cup is filled to a certain mark with the viscous substance so that the latter will cover the rotating cylinder to a depth of 0.6 or 0.7 of a centimeter when the viscosimeter cup is

raised into position for operation. After this is done, the thermometer is placed in its position within the cup and the latter covered with a sheet metal cover to reduce evaporation. The pointer of the revolution counter is next brought to the mark indicating 8 or 10 revolutions back of the zero point, in order that the rotating cylinder may make this number of revolutions before time is taken. Then the weight is raised into position by winding up on the drum the string to which it is attached. In the meantime the temperature of the bath is adjusted either by a gas burner underneath or ice within, depending upon the temperature desired. This crude means of control supplemented by patience and a little skill served to maintain the bath within half a degree of the required temperature. When this is attained, everything is ready for a determination, which consists essentially in noting the time required for 100 revolutions of the rotating cylinder. The weight is released and as the pointer of the revolution counter passes the zero mark, a stop watch is started. As the pointer passes the zero mark again, indicating 100 revolutions, the watch is stopped. It is important to note at this point that the rotating cylinder must be allowed 8 or 10 revolutions for overcoming inertia.

The calibration data were charted. In the case of each curve the middle and larger portion is a straight line. However, the ends of the 150-gram curve are bent a trifle and those of the 100-gram considerably more so. The lower bends are probably due to high speeds and consequent momenta of the rotating cylinder and falling weight as a result of low viscosities. The upper bends are probably due to variabilities or irregularities in the friction of the viscosimeter mechanism which become significant as the speeds of the cylinder and weights fall below a certain point. Subsequent experiences have shown the advisability of confining viscosity measurements to ranges within which the calibrating curves are straight lines. Outside of these ranges, especially in the regions of the upper bends, it was somewhat difficult to obtain duplicates which checked. However, the results indicate that the higher viscosities determined in this investigation by means of the 150-gram weight are worthy of confidence.

Materials

The materials used in this investigation consisted of a series of 11 flours milled from unblended wheats grown in different parts of the country. These flours are listed in Table I, together with historical data, experimental baking values, and chemical composition in terms of those constants which are ordinarily determined on a flour in control laboratories. Flour No. 9528 was milled in a Marvel Midget mill

under the writers' supervision. Flour No. 9716 was furnished by the Sperry Milling Company at special request. Flour No. 9327 was a commercial brand. The remaining samples were milled in a special mill under the supervision of Mr. Walter K. Marshall, of the Milling Division, United States Department of Agriculture, Washington, D. C. Mr. Marshall also supervised the collection of the wheats from which these flours were milled and performed all baking tests by methods described in Department of Agriculture Bulletin 1187 (1923). The chemical data on these samples were obtained by methods of the Association of Official Agricultural Chemists (1919). The writers desire to express to Mr. J. H. Shollenberger, to Mr. Marshall, and to Mr. C. B. Kress, of the Sperry Flour Company, their thanks for their invaluable assistance.

The use of these flours as sources of wheat starches afforded means of correlating starch viscosity with wheat variety, geographical source, chemical composition, and baking quality of flour.

Preparation of Wheat Starches

The following is the method by which starches were obtained from the above flours:

From 100 to 125 grams of flour were made into a stiff dough with tap water. This dough was allowed to stand under tap water for three-quarters of one hour in order to allow the gluten to ripen. The starch was then extracted from the dough by kneading the latter under a gentle stream of tap water. In this manipulation the gluten portion was held back, whereas the starch passed on with the water, which was collected in a beaker underneath. By this operation the starch was brought into a water suspension, usually of about one liter in volume. This suspension was next stirred up with enough sodium chloride to form a 1% salt solution to dissolve globulins which it might contain and to furnish means for testing the completeness of subsequent washings. The starch was then thrown out of the salt solution and washed with distilled water until the washings gave a negative test for chlorides. This work was all done by centrifuging, which proved to be quicker and otherwise more satisfactory than filtration. By centrifuging it was also possible to remove particles of gluten which had passed on with the starch when the latter was kneaded out of the dough. These particles always settled as a layer on top of the starch column in the centrifuge tube and could therefore be scraped off with a spatula flattened on the end.

After washing with water the starch was washed two or three times with 95% ethyl alcohol and finally three or four times with anhydrous ether. The centrifuge was used for these washings also.

TABLE I

MATERIALS USED, HISTORICAL DATA, BAKING VALUES, AND CHEMICAL COMPOSITION

Sample No.	Description	Class	Source	Water absorption	Loaf	Color of crumb	Texture of crumb	Ash of flour	Moisture in flour	Protein (N x 5.7)		
										Total	Salt soluble	Gluten (total minus salt soluble)
				%	c.c.	Score	Score	%	%	%	%	%
9167	Straight flour	H. R. W.	Kansas	60.6	2050	88.5	88.0	.48	12.6	10.51	1.68	8.83
9168	Straight flour	S. R. W.	Missouri	56.2	2030	92.5	91.8	.45	12.4	8.99	1.64	7.35
9255	Straight flour	H. R. S.	N. D.	59.7	2090	85.5	99.5	.59	12.2	9.49	1.67	7.82
9296	Straight flour	S. W. S.	Oregon	57.4	1990	85.8	88.0	.53	12.9	8.80	1.58	7.22
9297	Straight flour	W. Club	Oregon	53.8	1690	84.5	87.3	.48	12.6	8.68	1.47	7.21
9327	Commercial patent	H. R. S.	Minn.	60.6	2200	93.0	90.5	.39	10.2	9.5	1.46	8.04
9328	Commercial patent	H. R. W.	Kansas	60.3	2220	93.5	92.0	.38	10.5	9.8	1.40	8.4
9329	Commercial straight	S. R. W.	Penn.	57.1	2080	94.8	91.5	.41	10.6	8.4	1.41	7.0
9528	Marquis	H. R. S.	Idaho	65.3	2150	95.3	87.8	.508	10.18	12.42	1.75	10.67
9530	Durum straight	Durum	Composite	67.1	1880	91.0	93.5	.77	11.9	11.0	2.08	8.92
9716	Patent	S. W. S.	Utah	59.1	2090	98.3	88.0	.48	10.75	8.45	1.49	6.96

The starch was then transferred to a crystallizing dish which was placed over calcium chloride in a vacuum desiccator in which a vacuum of 3 to 4 centimeters of mercury was maintained until the loss in gross weight of the crystallizing dish and starch was less than one-tenth of one gram in 24 hours. This drying required from five to seven days, depending on the amount of starch and the shape of the dish. The starch, without being removed from the crystallizing dish, was then stored over calcium chloride in an ordinary non-vacuum desiccator, from which portions were weighed out directly for subsequent determinations. Starches so stored were found to contain from 3% to 5% of moisture as indicated by loss in weight as a result of drying at 102° for 16 to 18 hours at atmospheric pressure. The purity of starches prepared in this manner was judged by their nitrogen contents, which are given in Table II. It will be noted that these vary from 0.033% to 0.045%.

TABLE II

MOISTURE AND NITROGEN CONTENTS OF STARCH SAMPLES

Values Expressed in Percentages

	Moisture			Nitrogen		
Sample	No. 1	No. 2	Average	No. 1	No. 2	Average
9167	3.43	3.33	3.38	.037	.032	.034
9168	3.87	3.66	3.76	.033	.035	.034
9255	4.47	4.20	4.33	.038	.038	.038
9296	3.92	3.92	3.92	.030	.040	.035
9297	3.90	3.90	3.90	.036	.032	.034
9327	4.05	4.00	4.02	.046	.048	.047
9328	5.00	5.00	5.00	.040	.040	.040
9329	4.40	3.90	4.15	.050	.040	.045
9528	2.28	2.28	2.28	.035	.033	.034
9530	3.93	3.65	3.79	.045	.043	.044
9716	3.00	3.00	3.00	.032	.030	.031

Comparative Viscosities of Wheat Starches

The eleven starches listed in Table II were those used for the comparative study of wheat starches. The experimental work consisted in determining viscosities of pastes of each starch at 90° at four or five different concentrations ranging from 3% to 6% (approximately 2.85% to 5.75% on the moisture-free basis).

The technic.—The raw starch suspension of the desired concentration was poured into the viscosimeter cup which was then placed in its position. After all other adjustments necessary for viscosity determinations had been made as described in the method of standard-

ization, heat was applied to the bath by means of a microburner. During the rise in temperature, the suspension was kept uniform by an almost constant to-and-fro movement of the rotating cylinder. Below 90° this stirring was interspersed by a viscosity determination at every 10° rise in temperature in order to check the mechanical operation of the viscosimeter. These preliminary determinations at the lower temperatures were always made with the 100-gram weight. A change to the 150-gram weight was made only when the viscosity increased to such a value that the 100-gram weight was not able to produce 100 revolutions of the cylinder in from 150 to 200 fifths of one second. Above 90° a determination was made at every degree rise until a reading was obtained which was lower than the one preceding it. This decrease in viscosity usually occurred between 93° and 95°, and was taken as an indication of complete gelatinization. The temperature was then quickly adjusted to 90° by adding a little cold water to the bath and reducing the flame underneath.[3] In preliminary experiments it was found impossible to determine viscosities of pastes at 25°C. At this temperature the viscosity readings decreased with each successive determination. The number of determinations required to obtain constant readings varied from four to ten. This behavior may be explained on the assumption that cooled starch pastes are more or less plastic. In plastic materials the rotating cylinder tears down plastic structures or cuts paths which become wider with each successive determination. As a result the rotating cylinder encounters a progressively decreasing resistance, thus making impossible plasticity determinations by the Stormer viscosimeter. However, at 90° viscosity determinations were always constant, presumably because starch pastes are not plastic at this temperature and at the concentrations which were employed in this investigation. Absence of plasticity under these conditions will be discussed in a later section. The temperature of 90° also approximates more nearly that which prevails within the loaf at the time of baking. It seemed reasonable to suppose, therefore, that differences in starches which might be significant in the baking process would be more pronounced at 90° than at the lower temperatures. As a result of these considerations, 90° was selected as the temperature for making comparative viscosity determinations of starch pastes. When the paste had acquired this temperature, two or three determinations were made and the

[3] By this means of control it was possible to maintain the temperature of the paste at 90° ± 0.5°. It was found that variations in the temperature of pastes within these limits had no appreciable effect on their viscosities.

average was taken as the viscosity of that particular preparation. The entire determination was then duplicated on a second preparation of the same concentration.

Results

The resulting data are compiled in Table III. In this table the duplicates represent average viscosities in stop watch readings of fifth seconds of two separate pastes or preparations. The unmarked readings were obtained by the 100-gram weight. The readings marked by asterisks were obtained by the 150-gram weight. The averages of the duplicates were used for conversion into centipoise units. This was done by means of the calibration curves. These results are also represented by curves on Plates I and II. On Plate I viscosities were plotted to a logarithmic scale on the vertical axis against arithmetic concentrations on the horizontal axis. Following the conventional engineering practice, a straight line was then drawn as closely as possible through the points for each starch. From each of these lines ten pairs of values for x and y were scaled and used for plotting the curves on Plate II. The points shown on this plate are experimental and were located after the curves had been plotted.

Discussion

These data show first of all that differences exist among wheat starches. In Table IV viscosity values in centipoises at concentrations of 5.5% and 5.75% have been employed as numerical units for expressing these differences quantitatively.

As will be noted in Table III, a series of viscosity values has been obtained for each starch by making determinations upon its pastes in different concentrations. If the logarithms of these viscosities are plotted on the vertical axis against the corresponding arithmetic concentrations on the horizontal axis, as has been done on Plate I, the resulting points lie on a straight line which corresponds to the type equation.

$$\log y = mx + \log b$$

or

$$\log y - \log b = mx$$

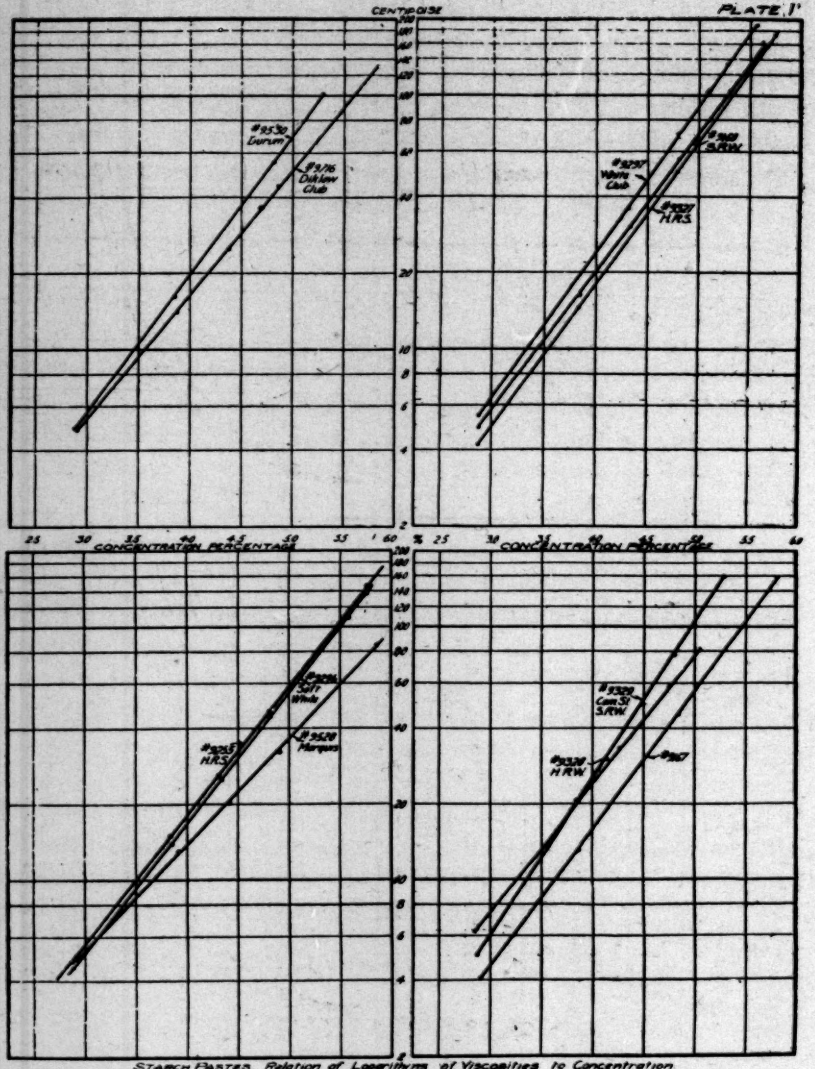
where y = viscosity
x = concentration
m = slope
b = interception point on the y axis

TABLE III

VISCOSITIES OF WHEAT STARCHES

Sample No.	Concentration percentage	Time for 100 revolutions Fifth seconds		Centipoise
	2.89	44,	44	4.0
9167	3.86	65,	65	13.0
	4.83	93,*	93*	45.0
	5.79	260,*	260*	158.0
	2.89	46,	47	4.9
	3.85	73,	72	16.6
9168	4.33	101,	103	30.5
	4.81	158,	160	56.0
	5.29	178,*	181*	104.2
	2.87	46,	...	4.8
	3.83	68,	70	15.0
9255	4.31	96,	96	26.0
	4.79	96,*	94*	46.5
	5.74	245,*	241*	146.5
	2.88	45,	...	4.5
	3.84	66,	69	14.0
9296	4.32	90,	90	25.0
	4.80	132,	133	44.5
	5.57	...	186*	109.0
	5.76	225,*	225*	135.5
	2.88	48,	48	5.5
	3.84	82,	80	20.0
9297	4.80	130,*	130*	70.5
	5.28	222,*	218*	132.0
	5.57	310,*	306*	188.0
	2.88	44,	45	4.2
9327	3.84	68,	68	14.5
	4.79	144,	142	50.0
	5.75	282,*	284*	172.0
	2.85	49,	50	6.2
	3.80	78,	77	18.8
9328	4.27	105,	109	33.0
	4.75	165,	110*	57.8
	5.70	326,	...	.....
	2.87	47,	47	5.0
	3.83	81,	82	20.5
9329	4.31	122,	119	39.0
	4.79	218,	216	77.5
	5.27	256,*	260*	157.0
	2.93	46,	46	4.8
	3.91	64,	67	13.0
9528	4.40	80,	80	20.0
	4.89	106,	104	32.0
	5.86	151,*	148*	84.5
	2.88	46,	46	4.9
9530	3.84	71,	72	16.2
	4.81	107,	107	55.0
	5.28	177,	177	103.0
	2.91	46,	...	4.8
	3.87	66,	66	14.0
9716	4.37	93,	88	25.0
	4.85	133,	132	44.5
	5.82	220,*	216*	131.0

PLATE I



STARCH PASTES Relation of Logarithms of Viscosities to Concentration

*Data from Table 3

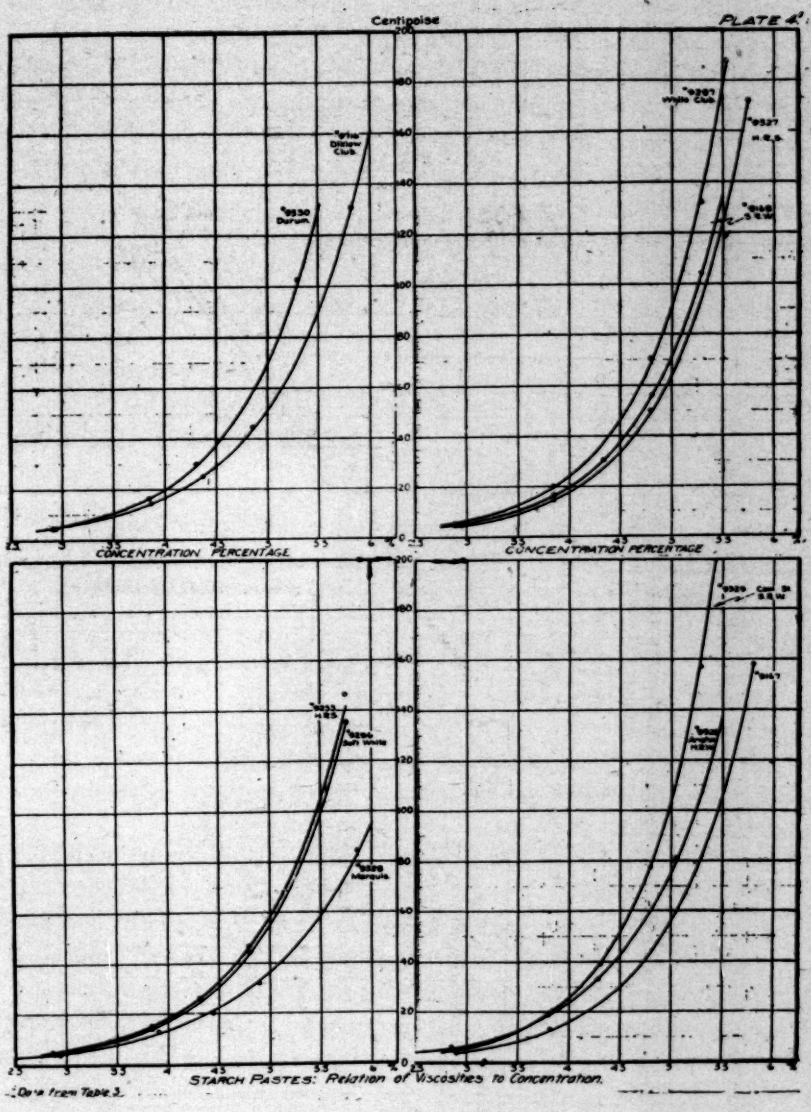

Centipoise
PLATE 4
CONCENTRATION PERCENTAGE
CONCENTRATION PERCENTAGE
STARCH PASTES: Relation of Viscosities to Concentration.
Data from Table 3.

TABLE 1V

VISCOSITIES OF STARCHES IN CENTIPOISES AND EQUATIONS EXPRESSING THE RELATION OF THE VISCOSITIES OF EACH STARCH AT DIFFERENT CONCENTRA-CONCENTRATIONS OF ITS PASTES

Sample No.	Class	Concentration 5.5% Viscosity in centipoises	Concentration 5.75% Viscosity in centipoises	Equations computed
9329	Soft Red Winter	213.5	.....	log y — log .0831 = .620 x
9297	White Club Winter	178.5	.....	log y — log .118 = .578 x
9328	Hard Red Winter	137.5	.....	log y — log .217 = .509 x
9168	Soft Red Winter	135.0	.....	log y — log .124 = .551 x
9530	Durum	132.0	.....	log y — log .128 = .549 x
9327	Hard Red Spring	124.5	171.5	log y — log .102 = .562 x
9167	Hard Red Winter	105.5	146.5	log y — log .105 = .545 x
9255	Hard Red Spring	105.5	141.5	log y — log .164 = .510 x
9296	Soft White Spring	100.0	135.0	log y — log .150 = .513 x
9716	Dicklow Club	91.0	121.0	log y — log .178 = .494 x
9528	Marquis	51.0	75.0	log y — log .276 = .424 x

It is obvious that the values for m and b are characteristic of the particular starch which the equation represents. In order to determine this equation for any starch, it is necessary to know the viscosities of its pastes at two different concentrations. If a larger number of values are available, the method of least squares should be employed. This may be done either graphically or analytically. As the graphic method had already been employed in plotting the curves, it was logical to use the same method in computing their equations. Accordingly, two pairs of values for x and y were scaled from the curves on Plate I and from these values the equations of the several starches were computed. These are given in Table IV.

The above equations conform to Arrhenius' (1917) modification of Einstein's equation for the viscosity of suspensions. Einstein's (1911) original equation is

$$\eta = \eta_0 (1+2.5\phi)$$

of which Arrhenius' modification is

$$\log \eta - \log \eta_0 = \theta \phi$$

where η is the viscosity of the suspension, η_0 the viscosity of the dispersion medium at the temperature of the observation, ϕ the fraction of the volume occupied by the dispersed phase, and θ a constant. It is apparent that this equation is identical with

$$\log y = mx + \log b$$

where $y = \eta$

$x = \phi$

$m = \theta$

$b = \eta_0$

The constant m is probably determined by properties of the dispersed phase, properties by which this phase affects the viscosity of the paste. Such properties may be degree of dispersion or size of the individual particles, their water-imbibing capacities, densities, shapes, and elasticities or plasticities.

In accordance with the theories of Einstein and Arrhenius, b represents the viscosity of the dispersion medium at 90°, the temperature at which the viscosities of the starch pastes were measured. In the case of starch pastes, it might seem logical to regard water as the dispersion medium. However, the viscosity of water at 90° is 0.3165 centipoises, whereas the values of b vary from 0.083 to 0.276 in the above equations for wheat starches. These differences may be explained by the possibility that only a portion of the starch contributes to the viscosity of the paste in the manner defined by ϕ of Arrhenius' equation. Such a portion would correspond to Samec and Haerdtl's (1920) and Maquenne's (1906) amylopectin or Meyer's β amylose. The other portion of starch would resemble the amylose of

Samec and Haerdtl which these investigators describe as producing a relatively non-viscous solution. If this be the case, the actual values for b would not be the viscosity of water but that of aqueous solutions of certain starch constituents. However, it is quite apparent that the computed values for b do not represent the viscosities of such solutions because they have been computed from values used for x which represents the percentage of total starch contained in the paste and not the amylopectin-like portion. In order that the curve may intercept the y-axis at the viscosity value of the dispersion medium, a value must be used for x which represents the amylopectin-like portion of the starch and not the entire starch as has been done on Plate I. As the slope of the curve is positive, it can readily be seen that the use of the latter and larger value for x has the effect of moving the curve toward the right and away from the y-axis and thereby lowering its interception with the y-axis. It is obvious that the use of an incorrect value for x affects the value of m as well as that of b, as the value of m is computed from that of x.

From these considerations it is obvious that the experimental technic in this study must be supplemented by additional data in the form of another equation simultaneous with $\log y = mx - \log b$, in order that m and b may be evaluated as defined by Arrhenius. It must be realized, therefore, that the values for m and b which have been obtained in this study are arbitrary and characterize starches accordingly.

Attention may be directed to the significance of the possibility of expressing by means of an equation, mathematically identical with Arrhenius' viscosity equation, the concentration of a starch paste as a function of its viscosity as determined by the technic employed in this study. The possibility of so doing is evidence of the absence of plasticity in starch pastes under conditions of consideration in this study. It is also a test or proof of the validity of the technic employed. A further proof of the validity of the technic is the consistency of the results obtained by the use of a 100-gram weight with those obtained by the use of a 150-gram weight. In the case of every starch the higher viscosities were determined by the use of a 150-gram weight, whereas the lower viscosities were determined by the use of a 100-gram weight. Still, the viscosity values obtained by the use of these two different weights fall on the same straight line when their logarithms are plotted against starch concentration, as was done on Plate I. This consistency may also be regarded as a check on the calibration of the viscosimeter.

Hydrogen-ion concentrations were determined electrometrically in 3% pastes of a sufficient number of starches to show the absence of correlation between hydrogen-ion concentration and viscosity. The hydrogen-ion concentrations varied from a pH of 5.2 to a pH of 5.6 in those pastes which were examined. No other attempts were made to ascertain direct causes of differences in viscosities of pastes prepared from different starches.

Correlations

The different values which have been obtained on this series of eleven wheat starches are wide and varied. However, there appear to be few correlations sufficiently uniform between them and other available data on these starches to warrant any definite generalizations. Perhaps the most uniform correlation is that between the growing habit of the wheat and the viscosity of its starch paste. This collection of eleven wheat starches is composed of five winter wheat starches, five spring wheat starches, and one durum starch. The last may be excluded from consideration, as durum wheat belongs to a separate sub-genus. In Table IV these starches are arranged in order of the viscosity of their pastes, beginning with the highest. As a result, four of the five winter wheat starches come first, whereas four of the five spring wheat starches come last. This arrangement presents a high degree of correlation between the growing habit of wheat and the viscosity of its paste. It is realized that No. 9327 and No. 9167 reverse this order. However, it will be noted that the values of these two starches are on the border line between those of spring and winter wheats, so that this reversal constitutes only a slight overlapping. Furthermore, No. 9327 is a commercial flour purporting to be made from hard spring wheat. However, it was learned that the mill producing this flour had blended some durum flour with this brand during the year this flour was produced, which may account for its position in the tabulation. It seems, therefore, that the growing habit of the wheat has a distinct effect on the colloidal properties of its starch as indicated by the viscosity of the paste. A possibility is here suggested of developing a method for distinguishing winter and spring wheat flours from one another on the basis of the viscosities of their starch pastes.

As another possible correlation may be mentioned the somewhat general association of high viscosity of starch paste with one or more of the following conditions:

1. Low loaf volume
2. Low protein content of flour
3. High temperature of growing locality[4]

Low viscosities are similarly associated with the opposite conditions. These correlations may be observed from an examination of Tables I and III.

It is probable that correlations may exist between the macaroni-making qualities of flours and viscosities of pastes prepared from their starches. Definite conclusions can not be drawn on this point, as data are not available on the macaroni-making qualities of the flours used in this investigation. However, it is a well-known fact in the trade that the products of durum wheats and Kansas hard winter wheats are particularly adapted for macaroni-making purposes. The high viscosities of the starch pastes of these wheats suggest the possibility that their superior macaroni-making qualities may be due to their starches as well as to their proteins. It may be possible, therefore, to supplement present methods for evaluating the macaroni-making qualities of a flour by a viscosity determination of a paste made from its starch.

Summary

1. A viscosimetric technic has been developed for determining the viscosities of starch pastes at 90° and at concentrations ranging from 2.85% to 5.75%.

2. Samples were collected of eleven flours milled from unblended wheats grown in the different wheat producing sections of the United States. Significant chemical data on these flours were determined by methods of the Association of Official Agricultural Chemists. Baking values were obtained by co-operation with the United States Department of Agriculture.

3. These eleven flours constituted the sources of the wheat starches which were investigated in this study.

4. Physico-chemical differences among the gelatinized pastes of wheat starches have been observed and measured quantitatively by the viscosities of their pastes.

5. The relation between the viscosity of a gelatinized starch paste and its concentration can be expressed by the equation

$$\log y = mx + \log b$$

where y = observed viscosity

x = concentration of starch

m and b being constants

[4] It is realized that the available data on the temperature of the growing season are rather indefinite, as they consist only of designations of the place of growth by states. However, it seems probable that the growing seasons of Idaho, Utah, and Oregon are cooler than those of Kansas, Minnesota, and Pennsylvania.

6. With one possible exception, wheats were observed to divide themselves according to their growing habits when arranged in the order of their gelatinized starch paste viscosities, starches of the winter wheats having the higher viscosities and those of spring wheats the lower. Durum wheat is not considered in this scheme of division.

7. The high viscosities of gelatinized starch pastes prepared from durum and Kansas hard red winter wheats suggest the possibility that the superior macaroni-making qualities of products of these wheats may be due to their starches as well as to their proteins. It may be possible, therefore, to supplement present methods for evaluating the macaroni-making qualities of a flour by a viscosity determination of its starch paste.

8. High starch viscosity was observed to be associated with two or more of the following conditions in the case of each flour:

1. Low loaf volume
2. Low protein content
3. High temperature of locality of growth

Low viscosities were observed to be similarly associated with the opposite conditions.

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CHARACTERISTICS OF THE 1923 HARD WINTER WHEAT CROP

By R. S. Herman and A. R. Sasse, Kansas City, Mo.

The 1923 crop of hard winter wheat from the Southwest has carried some rather interesting characteristics, which are, however, perhaps more pronounced from the milling than the baking standpoint.

The milling qualities have been very satisfactory in general, altho the tempering system has had to be adjusted; the wheat requiring different treatment from that given the several previous crops. The moisture content of the wheat has been higher than that noticed for several years, and the crop will average at least 0.6 of 1 per cent higher than the 1922 crop. Water penetrates the berry very readily in tempering, and most of the mills have had considerable trouble in keeping the moisture content of their flour within government limitations.

The baking quality of the flour has been very satisfactory from both an experimental and a commercial standpoint, since harvest. Sweating of the doughs has not been visible, and the freshly milled flour has given satisfactory baking results since the first new wheat was marketed.

The absorption of the 1923 crop is practically the same as that of the 1922 crop. The loaf volume, texture, and grain has been very satisfactory, while the fermentation period has been slightly shorter than that of several previous crops. The color of the unbleached flour is slightly creamier than that from the 1922 crop, with the crumb baking out to a very satisfactory bright tint. The ash content of the patents and straights has been lower throughout the crop, and approximates the factors found on the 1916 crop, averaging about two one-hundredths of 1 per cent lower than the 1922 crop. The protein content will average slightly higher for the entire crop, with the protein quality very satisfactory.

ABSTRACT OF THE REPORT OF THE REFEREE ON CEREAL FOODS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS

By C. E. Mangels

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The work during the last year was limited to a study of the moisture and ash methods. Samples were sent to several collaborators for moisture and ash determinations. The collaborators represented both institutional and commercial laboratories.

Moisture.—The collaborators were requested to determine moisture by three methods, (1) in vacuo at 100° Centigrade, (2) in air at 103-105° C. and (3) in vacuo at 70° C.

The results obtained may be summarized as follows: None of the methods showed as close concordance in results as is desirable. The results obtained by drying in vacuo at 70° were lower and less concordant than those obtained by the other two methods.

Drying in vacuo at 100° C. gave consistently higher results than drying in air at 103-105° C.

Other studies on the moisture methods may be summarized as follows:

The water-jacketed copper oven is a much less efficient dryer than the Freas electric oven and gave lower results even when samples were dried to constant weight at the same temperature.

Temperature rather than time of drying appears to be the important factor in drying in electric air ovens.

Variations in results by the vacuum method may be due to the degree of vacuum used. Experimental work conducted indicates that errors due to mechanical loss through suction are improbable.

Ash.—The collaborators were requested to determine ash by a method recommended by the former referee, C. H. Bailey. Quite consistent results were obtained. The maximum variation for the two samples being 0.03 and 0.036, respectively. The only objection to this method is the length of time required to obtain results.

Recommendation

1. It is recommended that the amplified vacuum method for moisture in flour and cereal products as recommended by Bailey in 1922, be tentatively adopted as the official method of the A. O. A. C.,

[1] Report presented at the annual convention of the Association of Official Agricultural Chemists on November 20, 1923, at Washington, D. C. The entire report will be published in due course in the Journal of the A. O. A. C.

and that the following words be inserted at the beginning of the second sentence "Replace cover." The method should read as follows:

Dry 2 grams of flour in a tared metal dish about 40 mm. in diameter by 25 mm. high, and provided with a tight fitting cover, to constant weight in a vacuum oven at a pressure of not to exceed 5 cm. of mercury and at a temperature of 100° C.

Replace cover, cool the dish in a desiccator, and weigh immediately when the dish and contents reach the temperature of the air in the laboratory.

Second reading as official method.

2. It is recommended that the amplified method for ash as recommended by Bailey in 1922, be adopted as the official method.

Second reading as official method.

3. It is recommended that the factor 5.7 be made official for protein in wheat as well as in flour. (Second reading).

4. It is recommended that the referee study methods of determining moisture in flour in order to determine causes of variation. The following points are suggested: (1) types of ovens, (2) containers, (3) temperature, (4) degree of vacuo, (5) size of sample.

5. It is recommended that the referee study the possibility of developing a rapid optional method for ash, which will be suitable for routine and commercial laboratories.

6. It is recommended that the referee study methods of sampling flour for analysis, and devise a uniform and practical procedure for sampling.

7. The recent work of Gortner and associates indicates that glutenin is the most important protein of the wheat kernel as affecting quality of flour. It is recommended that an associate or special referee be named to develop a method for determining glutenin content of flour and to devise methods for protein separations in flour.

8. It is recommended that particular attention be given to moisture and ash methods during the coming year, and if necessary, studies on other methods be delayed until moisture and ash methods are perfected.

The consideration of this report resulted in the following recommendations by the Subcommittee C, and approval by the convention of the subcommittee's recommendations.

It is recommended—

(1) That pending the conclusions of further study and collaborative work suggested by the referee in his report, no change be made

in the method for the determination of moisture in flour as printed in the present Book of Methods.[2]

Approved.

(2) That pending the conclusions of investigational and collaborative studies proposed by the referee, the present official methods for the determination of ash as now given in the Methods of Analysis[3] should not be changed.

Approved.

(3) That an associate referee be appointed to make a study of methods of sampling flour for analysis and to devise a uniform and practical procedure for sampling.

Approved.

(4) That an associate referee be appointed to develop a method for determining the glutenin content of flour.

Approved.

[2] Book of Methods, 1920, p. 167.
[3] Ibid.

THE PHYSICO-CHEMICAL PROPERTIES OF STRONG AND WEAK FLOURS. VIII. EFFECT OF YEAST FERMENTATION ON IMBIBITIONAL PROPERTIES OF GLUTENIN[1]

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Introduction

As the fermentation of a yeast dough progresses, certain physical changes take place in it which enable an experienced baker to judge with more or less accuracy the progress of the fermentation. This change during fermentation is generally considered a change in the gluten and is frequently spoken of as the "ripening" of the gluten.

It has been very difficult to correlate any chemical or physical change in the dough with this so-called "ripening." From the statements in the literature one would gather that no definite change is produced in the chemical properties of the flour proteins during yeast fermentation.

[1] Published with the approval of the Director as Paper No. 437, Journal Series, Minnesota Agricultural Experiment Station. The experimental work in connection with this paper was performed in the laboratories of the American Institute of Baking, in 1921, in connection with the studies carried out by F. A. Collatz on the production and disappearance of sugars in dough during yeast fermentation.

Several of the more or less recent contributions to the chemistry of bread may have a bearing on the so-called "ripening" process.

Jessen-Hansen[2] found that the largest loaf volume was generally obtained at a hydrogen-ion concentration represented by a pH of 5, and that if this hydrogen-ion concentration was not reached by the production of acids in normal fermentation, the addition of acids to the dough in sufficient amounts to produce this pH would usually result in an increased loaf volume.

Cohn, Cathcart, and Henderson[3] believe that this optimum hydrogen-ion concentration for bread baking is very important and describe a method using the color produced by methyl red on the freshly cut surface of the loaf, for telling whether or not the loaf was baked at the correct hydrogen-ion concentration.

Henderson, Fenn, and Cohn[4] found that the viscosity of a dough passed through a minimum at a pH a little below 5, and believe from their experiments that other things being equal a dough with low viscosity will yield a better loaf than one with high viscosity. They believe that one of the advantages of bringing a loaf to a pH of 5 before baking is the minimum viscosity of the dough at this hydrogen-ion concentration.

Bailey and Weigley[5] make the suggestion "that a part of the carbon dioxide produced at the outset becomes dissolved in the dough without effecting an appreciable expansion of the mass. In fact, it may be that ripening of the dough and its readiness for molding into loaves is in part related to the progressive solution of carbon dioxide in the dough during fermentation."

Collatz[6], and Bailey and Sherwood[7] have followed the progressive increase in the hydrogen-ion concentration of doughs during yeast fermentation.

This increase in acidity would tend to increase the activity of the yeast and of the diastatic enzymes present in the dough, for they show increasing activity as the hydrogen-ion concentration increases to a

[2] Jessen-Hansen, H. Etudes sur la farine de froment, I. Influence de la concentration en ions hydrogéne sur la valeur boulangére de la farine. Comptes-rendus des travaux Lab. de Carlsberg, t. 10, pp. 170-206. Fig. 4. (1911.)

[3] Cohn, E. J., Cathcart, H. P., and Henderson, L. J. The measurement of acidity in bread. J. Biol. Chem. v. 36, pp. 581-586 (1918).

[4] Henderson, L. J., Fenn, W. O., and Cohn, E. J. Influence of electrolytes upon viscosity of dough. J. Gen. Physiol. v. 1, pp. 387-397 (1919).

[5] Bailey, C. H. and Weigley, Mildred. Loss of carbon dioxide from dough as an index of flour strength. J. Ind. Eng. Chem. v. 14, pp. 147-150 (1922).

[6] Collatz, F. A. Flour strength as influenced by the addition of diastatic ferments. Amer. Institute of Baking, Bul. 9 (1922).

[7] Bailey, C. H. and Sherwood, R. C. The march of hydrogen-ion concentration in bread doughs. Ind. Eng. Chem. v. 15, pp. 624-627 (1923).

pH of 5. Henderson, Fenn, and Cohn find that the dough also shows a minimum viscosity at this hydrogen-ion concentration. We thus have these effects of the yeast fermentation on the apparent behavior of the dough of which the last named may be a direct effect on the gluten.

Experimental

Collatz,[6] using the viscosity method for determining the colloidal properties of the glutenin as developed by Gortner and Sharp, [8 9 10] found that malt flour decreased the hydration capacity of the glutenin to a marked extent.

The experiments reported in this paper were first undertaken in order to determine whether or not the presence of malt flour and malt extract in a dough could be shown to have any effect on the colloidal properties of the glutenin as normal fermentation progressed.

The baking procedure and formulas, together with other details, as well as the sugar content of the doughs, are given by Collatz[6] and will not be repeated here. The flour used in the experiments reported here was No. 1008, a patent flour milled from hard red spring wheat. Certain analytical data obtained with this flour are given by Sharp and Gortner.[11]

For the determination of the viscosity, enough dough was taken to correspond to 18 grams of the original moisture-free flour. This dough was kneaded with mortar and pestle with increasing amounts of distilled water until a thin paste was obtained. It was then made up to 500 cc. with distilled water, shaken at intervals for 5 minutes, allowed to stand 5 minutes, and the supernatant liquid decanted. An additional 500 cc. of distilled water was added and the process repeated. This washing process was repeated so that the suspension was treated with four 500-cc. portions of distilled water and then the final residue made up to 100 cc. and the viscosity as affected by lactic acid determined with a MacMichael viscosimeter. The washing out of the salts was carried out in this way instead of that described in the previous papers because about 1.5% sodium chloride had been added to these doughs and therefore greater care seemed necessary to minimize the salt effect on imbibition. The determinations in most

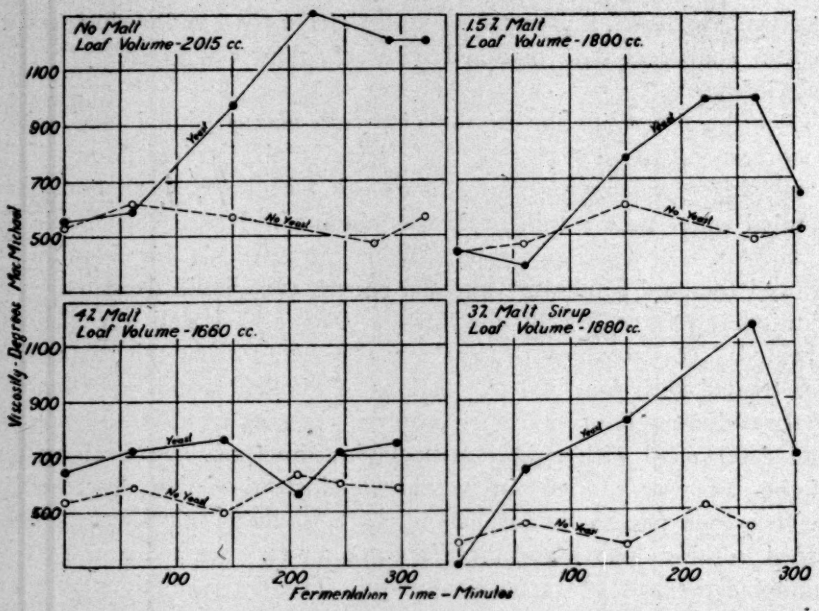
[8] Gortner, R. A. and Sharp, P. F. The physico-chemical properties of strong and weak flours. III. J. Phys. Chem. v. 27, pp. 481-492 (1923).

[9] Gortner, R. A. and Sharp, P. F. The physico-chemical properties of strong and weak flours. IV. J. Phys. Chem. v. 27, pp. 567-576 (1923).

[10] Sharp, P. F. and Gortner, R. A. The physico-chemical properties of strong and weak flours. V. J. Phys. Chem. v. 27, pp. 674-684 (1923).

[11] Sharp, P. F. and Gortner, R. A. The physico-chemical properties of strong and weak flours. VI. J. Phys. Chem. v. 27, pp. 771-788 (1923).

cases were made in duplicate. The viscosity readings are expressed in degrees MacMichael. The wire used was so adjusted that the reading of a 60% sucrose solution with an absolute viscosity at 25°C., according to Bingham and Jackson,[12] of 43.86 centipoise gave a reading of as nearly as possible of 87.7 degrees MacMichael. In the case of the mixtures having the higher viscosities, the residue was made up to 125 cc. instead of 100 cc. and the effect of such dilution on the viscosity was determined. The results expressed in Table I are corrected for dilution back to the basis of 100 cc. The experimental error is quite large in these experiments owing mainly to two causes, (1) the unequal removal of the added sodium chloride, and (2) the difference in mechanical treatment in preparing the original doughs and the kneading with the pestle in the mortar. The viscosity was determined on doughs containing none, 1.5, and 4% malt flour and 3% malt extract, prepared both with and without yeast. The results shown in Table I are expressed graphically in the figure.



The no-yeast doughs showed no changes in their imbibitional properties with time of standing that were greater than the experimental error. Two very striking changes in the yeast dough were, however, brought out by these experiments. As fermentation progresses there is a decided increase in the imbibitional capacity of the glutenin as

[12] Bingham, E. C. and Jackson, R. F. Standard substances for the calibration of viscometers. Bureau Stand. Sci. Paper No. 298 (1917).

influenced by lactic acid. In the case of the dough to which no malt was added, the increase amounted to more than 130%. This increase in viscosity is apparently less marked as the amount of malt flour added to the dough is increased.

These results show that malt preparations definitely decrease the imbibitional power of the glutenin during the period of ordinary fermentation. This is undoubtedly an evidence of the presence of proteolytic enzymes in the malt which act on the glutenin, changing its colloidal properties in a way which is unfavorable for bread making. That malt, especially if added in relatively large amounts, exerts a detrimental effect on the loaf is a matter of common knowledge among bakers.

Sharp and Gortner[10] have shown that the treatment of glutenin with alcohol greatly reduces the imbibitional strength of the glutenin. That a decrease in imbibition of the glutenin produced in this manner actually has an effect on the loaf volume was shown by Sharp, Gortner, and Johnson[13] who found that the mere treatment of flour with alcohol completely destroyed its baking strength. It would therefore be expected that if the malt preparations decreased the imbibitional power of the glutenin during the period of fermentation, they would also act unfavorably on the loaf volume, as was actually the case. The flour used in this experiment was shown by Rumsey[14] to have the most active sugar-producing enzymes of any of the flours he studied, so that as far as sugars in the dough were concerned, the flour itself was capable of producing all that the yeast needed and therefore the malts would show no beneficial effect in increasing the supply of sugars available for the yeast. The detrimental proteolytic effect of the malt would therefore be brought into prominence. This made the flour ideal for the study reported.

As the fermentation progressed, the viscosity of the mixture before the addition of lactic acid increased to a very marked extent. As the washing out of the salts progressed, the residue occupied a larger and larger volume until at last it was almost impossible to centrifuge it down to 100 cc. volume. The material took the form of a flocculent precipitate. This high viscosity of the suspension before the addition of lactic acid could be decreased to a remarkable extent by the addition of small amounts of various salts. It was thought that perhaps enough acid had been produced in the fermentation to cause imbibition of the glutenin after the electrolytes had been removed.

[13] Sharp, P. F., Gortner, R. A. and Johnson, A. H. The physico-chemical properties of strong and weak flours. VII. J. Phys. Chem. v. 27, pp. 942-947 (1923).

[14] Rumsey, L. A. The diastatic enzymes of wheat flour and their relation to flour strength. Amer. Inst. of Baking. Bul. 8 (1922).

TABLE I

EFFECT OF MALT FLOUR, MALT EXTRACT, AND YEAST ON THE IMBIBITIONAL PROPERTIES OF THE GLUTENIN OF FLOUR AFTER VARIOUS PERIODS OF FERMENTATION, VISCOSITY EXPRESSED IN DEGREES MACMICHAEL

	No malt			1.5% Malt, no sugar				
	Yeast, no sugar		No yeast, sugar		Yeast		No yeast	
	Fermentation time, min.	Viscosity, maximum	Viscosity, maximum	Fermentation time, min.	Viscosity		Viscosity	
					Initial	Maximum	Initial	Maximum
Mixed	0	560	538	0	...	439	...	434
First hour	60	594	622	60	...	387	...	467
First punch	150	975	570	150	...	775	...	605
Second punch	220	1311	...	220	...	988	...	488
Pan to proof	275	1207	470	265	230	990	10	477
To oven	318	1207	568	305	170	645	7	514
Loaf volume, cc.	2015			1800				

	4% Malt, no sugar					3% Malt, syrup				
	Yeast			No yeast		Yeast			No yeast	
	Fermentation time, min.	Viscosity		Viscosity		Fermentation time, min.	Viscosity		Viscosity	
		Initial	Max.	Initial	Max.		Initial	Maximum	Initial	Maximum
Mixed	0	6	647	7	535	0	5	290	6	380
First hour	60	7	719	7	589	60	9	650	6	450
First punch	140	15	760	12	498	150	28	820	6	370
Second punch	205	12	560	7	630	220	58	550	5	515
Pan to proof	244	39	710	8	600	260	410	1170	7	435
To oven	284	128	745	8	580	300	150	700	5	...
Loaf volume, cc.	1660					1800				

The hydrogen-ion concentrations of the suspensions at the time the loaves went into the oven and before the addition of lactic acid, were determined and found to lie between a pH of 4.88 and 4.97. This hydrogen-ion concentration is high enough to cause some imbibition, according to the work of Gortner and Sharp,[8 9] but is far from the hydrogen-ion concentration of maximum imbibition which occurs a little above a pH of 3.

This effect of the yeast on the glutenin and its viscosity has been investigated in the case of several other strong flours with essentially the same results, the increase in viscosity of a weak flour investigated was not so apparent. This change more or less parallels the "ripening" of the gluten and is probably one of the factors involved in the so-called "ripening" process. It may be that the points of maximum imbibition, as shown in Figure 1, are an indication that a definite stage in the ripening process has been reached, perhaps that the ripening process is completed. Several bakers who examined the loaves agreed that they had been over-fermented in each case.

These experiments indicate that it would be impossible to obtain gluten from fermenting dough, using distilled water as wash water, after fermentation had progressed to an appreciable extent; and that gluten could be obtained from fermenting doughs if sufficient electrolytes were present in the wash water. This point was investigated, using a dough containing 2% yeast and one containing all the other ingredients except yeast. The dough formula was the same as that used for the doughs in Table I, but it was necessary to use a different flour. The temperature of the doughs throughout the entire period was 27°C. At hourly intervals the gluten content of 25 grams of dough was determined, using distilled water as wash water in one case, and 1% sodium chloride solution in the other. The period of washing was arbitrarily taken as exactly 7 minutes, the temperature of the wash water was 22°C. The results are not so good as might be expected, perhaps because of the inexperience of the operator in washing gluten. The results are given in Table II.

Gluten could be obtained from the no-yeast dough with either distilled water or 1% sodium chloride throughout the entire period of the experiment, i.e., 24 hours. Beginning with the third hour, toward the end of the washing period there was a tendency for the gluten to go to pieces when using distilled water. This did not, however, interfere with obtaining a normal amount of gluten, although if the washing period had been continued a few minutes longer considerable difficulty would undoubtedly have been encountered. There was no

TABLE II

AMOUNTS AND MOISTURE CONTENT OF CRUDE GLUTEN OBTAINED FROM A YEAST AND A NO-YEAST DOUGH, USING DISTILLED WATER AND 1% NaCl SOLUTION AS WASH WATER. THE PERIOD OF WASHING WAS EXACTLY 7 MINUTES IN ALL CASES AND THE TEMPERATURE OF THE WASH WATER WAS 22°C. A 25 GRAM SAMPLE OF DOUGH WAS TAKEN IN EACH CASE.

Fermentation time	No yeast						Yeast					
	Distilled water			1% NaCl			Distilled water			1% NaCl		
	Gluten		Dry matter in wet gluten	Gluten		Dry matter in wet gluten	Gluten		Dry matter in wet gluten	Gluten		Dry matter in wet gluten
	Wet weight	Dry weight		Wet weight	Dry weight		Wet weight	Dry weight		Wet weight	Dry weight	
Hours	gms.	gms.	per cent	gms.	gms.	per cent	gms.	gms.	per cent	gms.	gms.	per cent
...	...	...	..		...	..	6.5	1.9	29	6.9	2.0	29
1	6.9	2.0	29	6.8	1.9	28	6.4†	1.7	27	6.5	2.0	31
2	7.3	2.2	30	6.8	1.9	28	6.1†	1.2	20	6.3	1.8	29
3	7.0*	1.9	27	6.9	2.0	29	6.2†	1.1	18	6.8	2.1	31
4	7.4*	2.0	27	...	...	..	7.0†	.08	11	...	...	..
8	7.2*	2.1	29	7.2	2.1	29	0.0	...	..	6.3	2.0	32
24	7.5*	2.2	29	7.5	2.3	31	0.0	...	..	6.1	2.0	33

*Slight change in physical properties of gluten at end of washing period.

†Marked change in physical properties of gluten at end of washing period.

apparent increase in this tendency to disperse after the third hour. The gluten obtained with sodium chloride solution had apparently the same physical properties during the whole period.

When washing the yeast dough with distilled water there was a change in the character of the gluten obtained, beginning with the first hour. Toward the end of the washing period the mass began to go to pieces and developed a very soapy, slippery feel. From this time on gluten was lost in the washing. The amount of gluten lost increased as fermentation progressed, altho the gluten obtained contained more than the usual amount of water, the proportion of water increasing as fermentation progressed. A part of the water in the later stages was not actually bound but was held mechanically between the particles. At the end of 8 hours no gluten was obtained. If the washing period had been shorter a more or less tenacious mass would have been obtained but it would have still contained an excessive amount of starch. Gluten of apparently the same physical properties was obtained over the entire period of 24 hours when 1% sodium chloride was used as the wash water.

These experiments indicate that yeast exerts a rather marked effect on the gluten during the period of normal fermentation.

Summary and Conclusions

1. Yeast has been shown to produce a marked change in the imbibitional properties of the glutenin as fermentation progresses.

2. The viscosity of a suspension prepared from the dough, with electrolytes removed, increases to a maximum as fermentation progresses. In a similar manner the viscosity of such a suspension treated with lactic acid markedly increases as fermentation progresses.

3. Malt flour and malt extract, owing to their proteolytic action on the glutenin, greatly decrease the above-mentioned effects of the yeast fermentation. The effect is more or less related to the amount of malt added and is also evidenced by a decrease in loaf volume.

4. As fermentation progresses it becomes impossible to wash gluten from the dough with distilled water, altho gluten can still be washed from the dough if sufficient electrolytes are present in the wash water.

5. These experiments emphasize the importance of the colloidal properties of the glutenin in bread making.

PHYSICAL TESTS OF FLOUR QUALITY WITH THE CHOPIN EXTENSIMETER

BY

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The ambition of the technician in every industry is to devise some simple physical test which will give an accurate and dependable index to the important properties of the materials with which he must work. Chemists have attempted with varying success to analyze these materials, and then correlate the results of such analyses with the results of physical tests. Composition of many materials is not an accurate criterion of strength, however, because of the differences that may exist in the physical characteristics of the several components. Chemical analysis does not, therefore, always give the satisfaction of a simple and direct physical test. This applies particularly to the development of methods for determining the strength, or resistance to stress, of materials. Mechanical engineers test the resistance to bending, tension, or compression with specially constructed apparatus. Manufacturers of textiles test the breaking strength of the fibers used. Millers and bakers would appreciate a similar test of flour which would afford an expression of its ability to produce an elastic dough capable of yielding large loaves of good texture.

For more than a century chemists have studied the composition of flour to determine the influence of its several components upon baking strength. Many of the numerous studies have been directed toward ascertaining the role of the gluten proteins. Certain general correlations have been established between the concentration of these proteins and the strength of flour, but many exceptions have been noted to the general positive correlation between these two variables. The importance of gluten, and the variations in the physico-chemical properties of one of its components, glutenin, have been stressed in the papers by Gortner and Sharp (1923a, 1923b) and Sharp and Gortner (1922, 1923a, 1923b). They employed a viscosimeter in determining variations in the water-imbibing capacity of glutenin as a criterion of its significant properties. Their studies establish the sensitive character of this gluten protein, and the ease with which certain of its characteristics may be modified.

Several efforts to evolve a suitable instrument for determining the physical properties of dough are worthy of note. One of the earliest

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devices used for this purpose was the aleurometer invented by Boland in 1848, to measure the expansibility of gluten. It consisted of a hollow tube containing a small piston and scale. The piston, drawn out its full length through the tube, showed 25 marks or divisions. Gluten washed from 50 grams of flour was placed in the tube, and this was heated at a constant and definite temperature by immersing it in a copper vessel filled with oil which in turn was heated by an alcohol lamp. In the cover of this copper vessel was soldered a cylindrical tube which was submerged in the oil, and into which the aleurometer would slide. The lamp was lighted and the temperature of the oil bath allowed to rise to 150°C., as indicated by a thermometer placed in the cylindrical tube. The aleurometer containing the gluten from 50 grams of flour was then placed in the tube; heat from the lamp was applied for 10 minutes, and the distance which the piston had risen was observed 10 minutes later. The increase in size, due to the generation of steam from the moisture in the gluten as determined by the strength and quantity of the moisture used, was measured in terms of the height to which the plunger rose.

Many flour testing devices, patterned after the Boland aleurometer, are now more commonly used than the original instrument. The farinometer invented by M. Kunis (1891) is clever and has been of some practical use. Foster's gluten tester (described by Wiley, 1898) is another device based on the principle of the aleurometer.

Kedzie (see Wiley, 1898) devised a "farinometer" while Jago (1911) described a viscometer to be operated in a somewhat similar manner. Briggs (1918) invented the "Perfekdo" viscometer for testing the relative stiffness of doughs. Henderson, Fenn, and Cohn (1918) developed a device for testing the effect of various substances upon the viscosity of doughs.

Wood and Hardy (1911) employed an entirely different principle in estimating the strength of flour, based upon the opacity of extracts to which iodine had been added.

Hankoczy's device, described by Kosutany in his book "Ungarische Weizen," and later (1920) in another publication, marked a new departure in the designing of equipment for testing the elasticity and ductility of gluten. In his device a thin sheet of gluten was clamped between two perforated plates, and on raising the pressure of the air on one face, the gluten stretched and expanded into a bubble through the opening in the opposite plate. Provision was made for measuring the volume of air required to produce the bubble of gluten.

Chopin's (1921) extensimeter, which was used in the studies reported in the latter portion of this paper, has not yet been described in English publications so far as we are aware. A translation of Chopin's paper made by Miss Le Vesconte is accordingly presented.

RELATION BETWEEN THE PHYSICAL PROPERTIES OF DOUGH SAMPLES AND THE BREAD MAKING

The making of bread is a complex phenomenon which has given rise to numerous investigations in the sciences of chemistry, physics, and bacteriology. Among the different viewpoints from which this phenomenon may be studied, there is one which does not appear to have been considered useful until now, that is, the relations which exist between the rising of bread and the mechanical properties of the flour dough.

It is well known that the different flour doughs, or the glutens extracted from these flours, have different elasticities, but the observations made on this subject remain purely empirical. The Boland aleurometer, often used by practitioners to determine the bread making value of a flour, estimates the residual elasticity of the gluten when raised to a high temperature, and is able to give only very uncertain results. Besides, the test should be made, not on the gluten but on the flour dough used in the bread making, for it is necessary to take into consideration the molecular cohesion of this particular substance.

My proposition is that a simple and general relation exists between the power which a flour dough possesses of being stretched into a thin membrane, and the specific volume of bread which can be obtained with this flour, this relation making it possible to determine in an exact and rapid fashion the baking value of a flour.

APPARATUS TO MEASURE THE MECHANICAL PROPERTIES OF PLASTIC MATTERS

My researches were retarded at the beginning by the necessity of building an apparatus to measure the mechanical properties of plastic matters, especially applicable to the study of flour dough, altho its use could be extended to several industries.

I have tried to form with a cylinder of dough, made in a uniform manner, a bubble covered with a thin surface, analogous to that which forms in the elementary part of the crumb of bread, and of large enough dimensions to make it possible to affect the two following measures:

a. The measure of the tenacity of the dough, estimated by the effort necessary to force this cylinder to take, in a constant time, a definite form.

b. The measure of the power of the dough to stretch itself into a thin membrane.

The conditions that must be realized in order that the tests be comparable are the following:

It is self-evident that the dough must be prepared under definite conditions. Because of the inconsistency in this matter, it is logical in using the apparatus to limit it to the small cylinder of dough being tested, and for the same reason the attachment of the cylinder should be as firm as possible. The cylinder should be kept at a constant temperature. Finally it is indispensable that the law of variation of the force to which the dough is submitted should be uniform in all trials, for these substances are only able to undergo one series of permanent deformations. These conditions are realized in a practical, satisfying manner in the apparatus shown in Figure 1, in a longitudinal diagram, and in Figure 2 in a photograph (omitted).

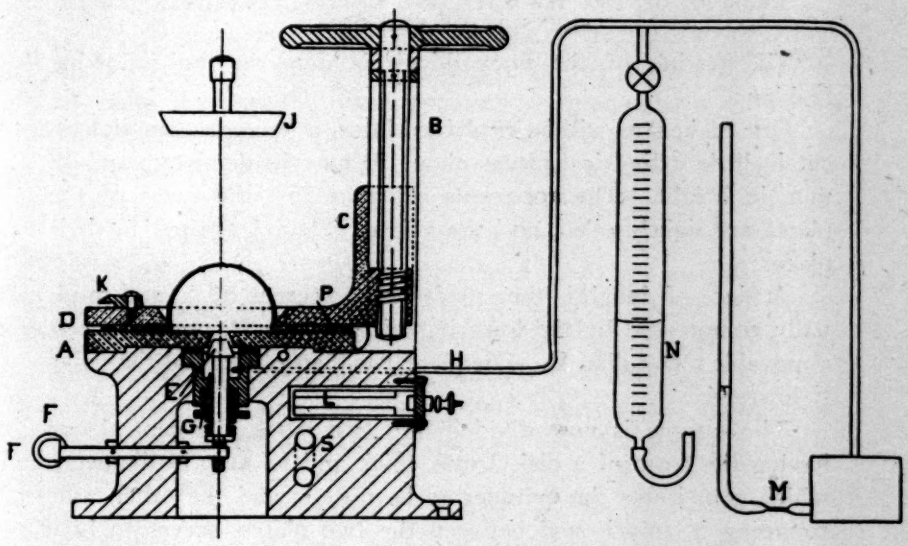

Fig. 1.

Fig. I. Diagram of the Chopin Extensimeter

This apparatus consists of a cast-iron foundation surmounted by a bronze plate, A, of circular form. The base supports a vertical column, B, on which the plate is able to move, which is part of the second bronze plate, D. It is possible to move this plate parallel to the first. At the center of the plate A, an opening of conical form is made, which may be closed by the valve of similar form, E, which is worked by the outside lever, F. The chamber, G, is united by the tube, H, to the observation instruments graduated at a reduced scale, and consisting of: a water manometer, M, provided with a reservoir to deaden the critical oscillations, and a glass measure, N, graduated in cubic centimeters and connected below by a rubber tube with a working flask containing water.

The plate D is also pierced in the center by a circular opening which may be closed by the lid, J, held in place by three swivels such as K. The base supports an electrical resistance to heat, L, connected to a rheostat, and a coil through which running water may flow to assure contingently the cooling of the apparatus. A thermometer gives the temperature of the plate A, and during the tests the plates A and B are put in contact.

MEASURE OF THE TENACITY AND OF THE COEFFICIENT OF EXENSION OF THE DOUGH

The testing of the flour dough is done in the following fashion:

One makes, as will be explained later, a homogeneous dough, cut in little cylindrical pieces about 50 mm. in diameter, and 18 mm. in height. The apparatus being at 25°, the faces of the plates are lightly oiled, and the valves E and J are put in their places.

A piece of dough is then placed in the center of A, and gradually compressed by the lowering of the plate D, until it meets a movable metal disc, P. The plate J is then raised and the valve E lowered.

The sample is now divided into two parts, the central one having the form of a disk 3 mm. thick and 58 mm. in diameter, which constitutes the cylinder to be tested; and the other, surrounding it, imprisoned between the two plates, serves to hold the test piece. Because of its small breadth, the dough almost instantly takes the temperature of the plates.

The working flask being put in the higher determined position, a little air is forced under the test-piece, to lift it. Then the air is allowed to pass freely. The manometer rapidly reaches

a maximum pressure which becomes stationary before diminishing at last gradually. The maximum pressure (P. in mm. of water) is a measure of the effort necessary to change the form of a membrane of dough, and makes it take the form of a definite spherical bubble. It is proportional to the tenacity of the dough. Its value has a significance only for a definite velocity of the flow of air.

The raising of the dough follows, and the membrane is seen to stretch, taking the form of a spherical bubble with a very thin surface (Fig. 2) of which the volume ceases to increase only when a rupture is produced on the surface.

The surface of the membrane at the time of the rupture serves as a measure of the coefficient of extension of the dough represented by E. The preliminary trials have permitted us to compare the respective values of the surface of the membrane and the volume of the flow of air. They are approximately proportional within experimental error so that it is practically accurate to make the reading of the volume of air at the moment of rupture, V, on the graduated measure, N.

The result given for E is an average of eight trials on testing pieces taken from the same dough.

We will notice that the displacement of the membrane always operates under identical conditions. It follows the law of the flow of water between the communicating vessels, and the stretching of the membrane causes only a feeble slowing-up in the flow of the liquid, 21 seconds instead of 19 seconds to attain a volume of 500 cc.

MECHANICAL PROPERTIES OF THE FLOUR DOUGH

A great number of trials have been necessary in order to fix the importance of the different factors which influence the results in order that the test piece of dough be representative in a uniform fashion of the flour from which it is taken.

We will give only the conclusions of these trials, giving some curves whose main object is to point out the meaning of the variations.

INFLUENCE OF TEMPERATURE

A flour dough was tested at different temperatures. The average results are shown in Graph 1 (Fig. 3). (Graph omitted.) It is seen that the dough becomes less tenacious and more easily stretched when the temperature increases and that the effect is considerable.

INFLUENCE OF THE COMPOSITION OF THE DOUGH

Flour doughs are tested that hold from 40 to 65 per cent water, the primary humidity of the flour being 15 per cent. The results are shown in Graph 2 (Fig. 3). (Graph omitted.)

INFLUENCE OF THE MANNER OF WORKING THE DOUGH

The work necessary to render the dough homogeneous affects its cohesion and consequently the results. In order to measure the action, we have measured the values of P and E obtained from dough submitted to three successive compressions in the apparatus. These values are shown in Graph 3 (Fig. 3). (Graph omitted.)

AGE OF FLOUR—TIME OF STANDING OF DOUGH

We will only indicate the change in mechanical properties of a flour with time, a change especially great during the first days after milling.

On the other hand, the elastic properties of a dough allowed to rest after leaving the mixer, increase, principally during the first half hour.

Finally, it is probable that the composition of the water used in the mixer has an equal influence on the results.

These different results can be interpreted by saying that the values of P and E depend, for a given flour, on the degree of cohesion of the dough. A compact dough, having a greater cohesion, is tenacious, and necessitates a greater effort to deform; on the other hand, it has only a feeble power of stretching into a thin membrane.

The results conform with the fact well known to bakers, that a dough with a high percentage of water, if placed in a relatively high temperature, swells more rapidly and more completely than a dough mixed or fermented at a low temperature.

It gives, finally, a perception of the many factors which intervene in the course of bread making, and make possible the obtaining of comparable accurate results.

PREPARATION OF A HOMOGENEOUS DOUGH

The preceding observations have permitted us to define the following conditions necessary for obtaining a homogeneous dough characteristic of the tested flour. Three hundred and thirty-three grams of flour (supposedly with a moisture content of 15 per cent) are mixed in a small mechanical mixer with 163 grams of water at 25°, and 5 grams of sodium chloride.

Small variations of the amount of water in the flour, of the order of 1 per cent, more or less, are admissible, without changing these proportions. If the percentage of water is unknown, it is necessary to determine the approximate value, in order to make the dough to the same total humidity.

The mixing is carefully done for eight minutes. The dough is then formed into a cylinder about 65 millimeters in diameter, and allowed to stand for twenty minutes. In order to proceed to the tests, one cuts with the help of a metal cylinder, as they are needed, test pieces 50 millimeters in diameter and 18 millimeters thick.

This technique allows the forming of lumps of dough having a definite cohesion, but under conditions that exclude any important manual pressure in their preparation.

We give below, as an example, the results of five trials the same day with a flour. The tenacity of the dough (P in mm. of H_2O); the volume of rupture of the membrane V in cubic centimeters (prop. to the coefficient of extension, E), and the square root of the volume, which serves as a measure, as we will soon see, of the index of the bread making inflation of a flour.

1.	Vr.:	350	370	410	340	360	350	360	390
	$\sqrt{}$ Vr.:	18.7	19.2	20.2	18.5	19.0	18.7	19.0	19.7
		P aver.: 41.2				$\sqrt{}$ Vr.=aver.: 19.12			
2.	Vr.:	300	330	360	390	370	260	400	340
	$\sqrt{}$ Vr.:	17.3	18.2	19.0	19.7	19.2	16.1	20.0	18.4
		P aver.: 43.0				$\sqrt{}$ Vr.=aver.: 18.50			
3.	Vr.:	370	410	420	360	350	360	320	420
	$\sqrt{}$ Vr.:	19.2	20.2	20.5	19.0	18.7	19.0	17.9	20.5
		P aver.: 41.8				$\sqrt{}$ Vr.=aver.: 19.36			
4.	Vr.:	380	480	250	420	410	420	380	400
	$\sqrt{}$ Vr.:	19.5	21.9	15.8	20.5	20.2	20.5	19.5	20.0
		P aver.: 41.5				$\sqrt{}$ Vr.=aver.: 19.74			
5.	Vr.:		280	300	340	400	450	420	400
	$\sqrt{}$ Vr.:		16.7	17.3	18.4	20.0	21.2	20.5	20.0
		P aver.: 42.9				$\sqrt{}$ Vr.=aver.: 19.15			

The average value of the estimate of bread making value is 19.17. The average variation between this probable value and the average values obtained by each trial is 1.5 per cent, and the maximum variation is 3.5 per cent. The volumes of rupture show rather large errors due to the inevitable defaults in the homogeneity of the dough. The error is somewhat reduced because

the square roots of the volume alone are important in our determinations. Finally, the average of the eight successive trials tried with the same dough, tested in a definite interval of time, gives the value of the estimate of the inflation with a very satisfying approximation.

We are able under these conditions to take up the principal part of our study.

RELATION BETWEEN THE COEFFICIENT OF EXTENSION OF THE DOUGH AND THE BREAD MAKING INFLATION

The trials include:

In the first part, the measure of the tenacity of the dough, (P in mm. of water) and the measure of the coefficient of extension of the dough, E, numerically equal to the surface of the membrane at the instant of rupture, proportional to V. The numbers adopted are the average of tests made with the extensimeter apparatus on a dough prepared as explained above.

They include on the other hand, the obtaining of four small loaves made from this flour, in conditions of bread making sufficiently similar, and the measure of the apparent specific volumes of these loaves. The bread making tests and the extensimeter measures are made as far as possible on the same day.

BREAD MAKING—METHOD OF OPERATING

A small mechanical mixer holding 2 kilograms of dough and an electric oven built especially for these tests which allows bread to be baked at a temperature measured by a pyrometer, are used. This temperature is regulated by a rheostat. The cooking is done in a *current of vapor* coming from a chamber heated by a second electrical resistance.

The tests are made by an experimental baker who worked in his own way in that which concerned the kneading and the length of fermentation brought about by a dry yeast in excess, but who was instructed to form the loaves of dough of 175 grams in weight and to cook them for eighteen minutes at 270 degrees. The specific volume of the bread was obtained by weighing and by displacing little round seeds of known density. This volume is expressed in cubic centimeters per hundred grams of bread.

LAW OF THE EXTENSIBILITY OF FLOUR DOUGH

The results obtained are shown numerically on the tables following, with the exception of some preliminary trials which are of no value.

It will be noticed that no direct relationship exists between the tenacity, P, of dough and the bread making inflation. This does not surprise us, for the dividing up of the dough during bread making is infinitely slow, and the infinitesimal gaseous pressures are able by themselves to effect deformations which are also slow in being established.

There exists on the contrary a simple relationship between the bread making inflation and the coefficient of extension of the dough, E. This relation is shown clearly on Graph 4 (Fig. 4), (Figure omitted) where the specific volume of the bread is taken as ordinates and on which we have taken as abscissae the square roots of the coefficient of extension.

TABULATION OF TESTS CORRESPONDING TO CURVE 4

No.	Date		E	$\sqrt{E}$	P	Volume of 100 gr. bread	K	Percentage error
1.	August	8	234	15.3	36	359	17.9	+ 7.3
2.	August	21	112	10.6	81	274	17.8	+ 6.7
3.	August	24	199	14.1	53	341	18.1	+ 8.5
4.	August	25	199	14.1	53	331	17.4	+ 4.3
5.	August	25	90	9.5	..	259	18.3	+10.0
6.	August	28	264	16.2	37	380	18.2	+ 9.1
7.	August	28	77	3.7	80	228	16.3	— 2.3
8.	September	2	186	13.6	36	326	17.7	+ 6.1
9.	September	13	206	14.3	45	313	15.9	— 4.7
10.	September	15	239	15.4	40	339	16.4	— 1.6
11.	September	16	250	15.8	41	371	18.0	+ 7.9
12.	September	16	239	15.5	40	338	16.4	— 1.8
13.	September	17	220	14.8	43	314	15.5	— 7.0
14.	September	17	116	10.7	69	214	12.0	....
15.	September	18	116	10.7	69	230	13.5	—19.0
16.	September	18	254	15.9	27	338	15.9	— 4.4
17.	September	21	169	13.0	51	270	14.3	—14.0
18.	September	*	*	5.2	160	142	11.0	....
19.	September	24	270	16.4	41	363	16.9	+ 1.3
20.	September	30	229	15.1	40	341	16.9	+ 1.3
21.	October	1	241	15.5	40	341	16.5	— 1.1
22.	October	2	270	16.4	25	358	16.6	0.0
23.	October	2	126	11.2	80	238	13.6	—18.0
24.	October	22	284	16.8	35	348	15.6	— 6.5
25.	October	23	284	16.8	35	358	16.2	— 2.9
26.	November	6	244	15.6	33	343	15.9	— 4.7
27.	November	9	50	7.4	80	217	18.6	+11.5
28.	November	10	146	12.1	32	302	17.9	+ 7.3
29.	November	15	212	14.5	29	328	16.8	+ 0.7
30.	November	17	277	16.6	44	372	17.3	+ 3.7
31.	November	17	176	13.2	32	317	17.5	+ 4.9

*Approximate.

The thirty-one representative points of the tests may be drawn as a straight line, of which the ordinate at the origin is exactly equal to the specific initial volume, V, of the unfermented dough. (The differences of density are negligible.) In calling V the final specific volume of the bread and R a coefficient of proportion, this relation may be written:

$$V - V_0 = K \sqrt{E}$$

We have placed in the table in the next to the last column the value of K. If one excepts from the thirty-one tests, the tests 14 and 18, for which normal development could not be obtained, 16.68 is found as the average value of K. and yields the following errors by referring to this average:

14 trials give K with an error between 0% and 5%
11 trials give K with an error between 5% and 10%
2 trials give K with an error between 10% and 15%
2 trials give K with an error between 15% and 20%

Finally, the average error results at 6.24%.

The oven was also used to cook dough of 600 grams, of which the mass was a little too large with reference to the thermal capacity of the oven, and which for that reason did not reach complete development, the mixture remaining dry in the center of the bread. The tests satisfy the relation.

$$V\text{-}V_0 = KE^{0.4}$$

But this is an abnormal case, for the loaves made with 600 and 1100 grams have been baked in an oven of larger dimensions and their inflation satisfies the relation (1) with an approximation of the same order.

This relation is then general, and defines the law of the bread making inflation which may be given.

The difference between the specific volume of the bread which may be obtained with a flour, and the initial specific volume of this flour dough, is proportional to the square root of the coefficient of extension of this dough when stretched into a thin membrane. If one takes into account the difficulties met with in such tests, made during a period of several months, and that the thirty-one tests were made with very different flours ranging from the poorest grade to the best products of the mill of very glutenous wheat, we are led to conclude that this law approximately represents the complex phenomena of bread making inflation in the essential ways, and that the baking value of a flour is able to be predetermined in an exact fashion by this process.

It is understood that this law will not apply in the abnormal case of a non-alcoholic fermentation, which may alter appreciably the glutenous matter.

MECHANISM OF BREAD MAKING STRENGTH

Let us show how it is possible to apply the results just obtained to an examination of the formation of the crumb.

In a dough properly kneaded and mixed with yeast, the fermentation affects all the dough. Because of the great excess of

yeast and leavening used and of the small weight of gas necessary it is possible to consider fermentation as a chemical reaction which develops quantities of carbonic acid superior to the needs. It is possible, then, to say that the final volume is not, in general, affected by a greater or less activity of fermentation, which should simply be stopped at the proper time by the baker.

The division of the dough, which is affected by the formation of a large number of cavities of very different dimensions, will be in proportion to the ability of the dough to be converted into thin membranes separating the adjacent cells. At the end of the baking, the dough submits to a second very rapid increase in volume soon stopped by the forming of an outside crust. This increase in volume which completes the work of fermentation is as great as the membranes of the openings are able, without rupture, to stretch out. It appears, then, in an evident manner that the mechanism of the forming of the crumb of the bread is directly related to the ability which the dough possesses to develop into a thin membrane, and our results lead us to this daily verification that a loaf is as much light as the crumb is finely divided into a thin membrane.

RELATION BETWEEN TENACITY OF DOUGH AND MAKING INTO BREAD

It was noticed that the tenacity of the dough could be measured by the use of the extensimeter, by the pressure, P, necessary to deform the membrane in all determined conditions. We have stated that this increase is proportional to the ability which a flour possesses of absorbing water in the mixing machine, and permits in consequence a method of measuring the yield able to be obtained with a flour.

The baker added water to the flour until the dough had a consistency which appeared satisfactory. It is then on a statement of mechanical nature that he bases his appreciation. When the extensimeter, which operates on a dough made with a constant percentage of water, indicates a small value for P, it means that his dough is slack, and that the flour is not able to take up much water in the mixing machine. The inverse is true for a hard dough (P high). It is then possible to trace a curve relating the value of P and the percentage of water most favorable in bread making. We have endeavored to correlate the necessary elements in this curve.

INFLUENCE OF HEAT ON THE INDEX OF BREAD MAKING INFLATION

This influence is shown on curve 5 (Fig. 5). (Figure omitted.) A flour is divided into parts, warmed for twenty

minutes at a temperature shown on the abscissae. It is seen that the lowering of the elastic qualities of the flour is especially noticeable at about 50°. This action is known in milling, where a greater tension of the cylinders or too many openings to the converters produce an analogous effect, by raising the temperature of the milled products which result from it.

The control of the bread making value of a flour has been made so far either by studying the gluten content, showing what is given to the first approximation but which is not able to measure the variable specific elasticity of the different kinds of gluten or the method in which the gluten is divided in the dough, or by the bread making tests, long operations, the results of which are hard to compare.

In using the apparatus described in this study, and in defining the conditions necessary to make the results obtained quite characteristic of the mechanical properties of a flour dough, we have established the relation which exists between the bread making inflation and the coefficient of extension of the dough. As a result of this relation, the process makes it possible to determine rapidly, in an exact manner, the index of bread making inflation of a flour, as it would be in bread.

Let us notice in conclusion that the peculiar interest which men have always taken in wheat flour comes from the faculty this flour has of giving a raised bread. The law of bread making inflation which we have shown in this study ought, then, to serve as a guide to the miller or baker who tries to alter as little as possible the original elastic qualities of the wheat.

EXPERIMENTAL

THE PROBLEM

Through the courtesy of the Washburn-Crosby Company, a Chopin extensimeter which they had recently purchased was made available to us, and this was used in the studies reported in this paper. It was first necessary to standardize the method of testing with this apparatus, the probable error of the means of each group of tests with the same flour being incidentally calculated. After experience was gained in the manipulation of the instrument, the effect of the following variable upon the extensibility of dough was investigated:

a. Prolonging mechanical treatment in mixing the dough.
b. Increasing the proportion of water in the dough.
c. Adding starch to the flour.
d. Varying the hydrogen-ion concentration of the dough.

e. Treating the flour with chlorine.

f. Adding "flour improvers."

g. Fermenting with yeast.

h. Correlating extensibility readings with the results of baking tests of several flour samples.

PREPARING THE DOUGH SAMPLE

A mechanical mixer was employed in preparing the dough to insure that the mixing was uniform, and a fixed procedure was followed in subsequent handling of the dough. This was necessary, as the greatest difficulty in securing comparable results with the extensimeter seems to exist in the production of uniform doughs.

A 350-gram sample of flour was used in each test, this being the least that could be mixed in the kneading machine. This afforded sufficient material for ten tests with each dough, and our computations indicated that the probable error of the mean of this number of tests was small enough to make the mean acceptable as an index of the properties of the dough. Doughs were mixed for exactly eight minutes, which Chopin has stated is the least time in which the preparation of a homogeneous dough could be assured. The quantity of 2.5 per cent sodium chloride solution used in mixing the several doughs was varied with the absorption in the effort to produce doughs of the same relative consistency.

The mixed dough was removed from the machine, rolled into a sheet about 18 millimeters thick on a glass plate, brushed lightly with oil, covered with a damp cloth, and allowed to stand for 25 minutes. This procedure differed slightly from that of Chopin, who rolled the dough into a cylinder, sections of which were cut for the several tests. Chopin thus secured pieces with freshly cut surfaces for each test, which is advantageous in a measure. The lightly oiled surface of the dough, as prepared in our procedure, did not crust or dry appreciably, however, and we were enabled to secure sufficient material for ten replicate tests with each dough.

The time that the dough was permitted to stand after mixing appeared to be of importance, as in two instances, when the tests were made after sixty minutes, the extensibility readings were appreciably higher than the mean of similar doughs which stood for the standard period of twenty minutes.

TESTING WITH THE EXTENSIMETER

The temperature of the extensimeter was first brought to 25°C. While the dough was at the temperature of the room, it doubtless responded quickly to the temperature of the extensimeter when pressed into the thin sheet in which form the test was made.

The plates were lightly oiled, since either a very thick coating or a portion of surface that is not oiled tends to diminish the reading in terms of extensibility. A test piece was then cut from the dough sample, with a cylinder about fifty millimeters in diameter. This was placed on the bronze plate A, both valves being closed, and the upper plate was lowered until the dough had been pressed into a thin sheet the thickness of the metal stop (3 mm.) placed between the plates. The valves were then removed. The dough, as Chopin describes it, was then "divided into two parts, a central part, having exact dimensions of three millimeters thick and fifty millimeters in diameter, and an outer part, imprisoned between the two plates and serving to hold the test pieces." It is true that some of the outer piece is loosened somewhat, depending on the oiling of the plates, and the elasticity of the dough.

The water having been drained from the measuring tube, N, to the zero mark, the rubber tube, H, was clamped shut, and the tube was then connected with the manometer and testing apparatus by turning the three-way stop-cock at the top of N. This stop-cock allows air to enter the measuring tube from the outside while it is being drained, but when turned allows the water, as it enters the tube from below, to force the air into the testing apparatus.

Two small metal tubes lead to the measuring tube from the bottle above; the larger of which may be closed by a clamp. The smaller tube allows the water to flow at such a rate that, with the working bottle in the upper position, it will flow from the zero mark on the measuring tube to the twelfth division in twenty seconds. When the larger tube is opened, the water will flow through the two tubes at a rate that it will reach the twenty-fifth division in twenty-three seconds.

When the test-piece of dough was in position, the stop-cock turned, and the bottle raised to the position above the apparatus, the test was made. The larger tube was held closed with the clamp by the right hand, while the rubber tube connected with the elevated reservoir bottle was unclamped with the left hand. As the water flowed into the measuring tube the dough was forced from contact with the lower plate and began to form a bubble. The water in the manometer rose quickly to a maximum pressure, and began to fall as the disk of dough was lifted from the bronze plate. This maximum reading of the manometer was the one taken as a measure of the tenacity (P) by Chopin. A recording manometer has since been provided by Chopin, but was not received in time to be used in these experiments.

As the water in the manometer began to fall, showing that the bubble was separated from the plate, the clamp was slowly lifted from

the larger tube, and the bubble began to stretch. If the clamp was lifted too quickly, the dough membrane was likely to begin to stretch at some weak point, forming an uneven bubble that would break quickly, giving a low reading of elasticity. If the clamp was lifted too slowly, or was not lifted, the bubble might become as large as the average or slightly larger, but the extra time necessary for the bubble to rise would allow the dough to become dry and less elastic.

In a satisfactory test, the dough formed a well-rounded bubble, stretching into an extremely thin membrane which at last broke, developing several small holes. The rubber tube was then quickly clamped shut, stopping the flow of water, and the reading in the measuring tube was taken. The measuring tube was graduated to give directly the square root of the volume of the water in the tube, or the value of E spoken of by Chopin and which he found to be directly proportional to the increase in specific volume of the bread during a baking test.

After the test the stop-cock was turned to admit air from the outside, the bottle was lowered, and the measuring tube drained. The dough was then removed and the plates were oiled for the next test.

To make a series of ten tests on one sample of dough required from fifty to fifty-five minutes, including ten minutes for mixing the dough, twenty-five for the dough to hydrate, and from fifteen to twenty minutes for an experienced operator to make the tests. It has been the practice in most of this work to test two dough samples simultaneously. After the first dough had stood for ten minutes, a second dough was mixed, and was rolled out just before the first dough was ready to be tested. The second dough would then be ready to be tested after the tests on the first one were completed, making it possible to test two samples in one hour and ten minutes. More recently it has seemed advantageous to test three doughs simultaneously, completing the three tests in one hour and forty minutes.

EXPERIMENTAL VALUE OF THE RESULTS

After the method of mixing the dough and making the test had been standardized, twenty-five doughs from the same flour were tested, ten tests being made on each dough, and the standard deviation and the probable error of the mean of each series were calculated. The probable error of the mean for ten tests on a single sample of dough was found to be approximately one per cent, showing that the method of testing the extensibility gives a fairly accurate knowledge of the strength of an individual dough. It is more difficult in mixing a dough, however, to duplicate all the conditions that affect the properties of a substance as sensitive to treatment as such material. This

causes a greater deviation between the readings on different doughs from the same flour, making the value of the test depend on the uniformity of preparation of the dough sample. In order to give an indication of the number of doughs necessary for a fair test, the deviation between the average of five tests and of twenty-five tests was calculated. The results are shown in Table I.

In this work it was the practice, when sufficient flour was available, to average the tests on at least two sample doughs when the results were close, and to make more tests if the results were not close. During the latter part of the work it was possible to make the readings check more closely than in these data.

EFFECT OF MECHANICAL TREATMENT ON DOUGH STRENGTH

The physical properties of an emulsoid gel are dependent in part upon the degree of dispersion of the colloidal particles. The degree of dispersion may be affected by time, temperature, or mechanical treatment. Buglia (1908) found that the viscosity of milk could be increased by increasing the degree of dispersion of the fat on projecting it in a stream against an agate plate. Stevens (1922), in a paper on rubber, states that there is a gradual change in the colloidal properties of rubber, depending on the mechanical treatment it has undergone. As bread dough undergoes a vigorous mechanical treatment in mixing, one would expect a change in the colloidal properties after prolonged mixing. Tests of a series of doughs mixed for different periods of time showed that this change did take place, and that the extensibility was decreased appreciably by increasing the time of mixing from eight minutes to sixteen minutes, and continued to decrease with a longer period of mixing. These results indicate that in commercial bakeries it is quite possible that prolonged mixing of the bread dough may destroy the cohesiveness of the gluten and thus be detrimental to the bread.

The results, given in Table II, are the average of the readings for ten tests of each of two doughs mixed with the same flour.

TABLE I

Number of test	Readings with Replicate Doughs Tested by the Extensimeter										Mean	Standard deviation	Probable error of mean
	1	2	3	4	5	6	7	8	9	10			
1	20.1	18.3	17.7	16.0	17.4	18.0	18.6	16.4	15.7	20.3	17.85	1.530	.326
2	17.9	19.2	19.6	18.7	19.9	17.9	19.6	19.8	18.7	18.4	18.99	.715	.152
3	19.3	17.8	17.8	18.3	16.1	17.8	19.8	18.0	20.2	19.3	18.42	.920	.196
4	16.8	16.8	17.8	17.3	16.6	17.8	17.8	19.2	16.8	17.7	17.46	.602	.165
5	17.0	19.2	18.1	19.4	20.8	19.4	18.3	15.4	19.5	19.6	18.67	1.460	.311
1st five	....	....	....	....	....	....	....	....	....	....	18.28	.686	.207
6	18.3	18.8	18.5	17.3	18.1	16.2	17.2	17.1	16.5	15.5	17.55	.911	.194
7	19.2	18.7	18.7	18.5	18.2	20.1	18.2	18.3	18.4	18.2	18.65	.564	.120
8	18.2	18.3	16.1	16.7	15.7	16.4	15.1	17.8	15.3	19.7	16.83	.740	.158
9	17.2	18.3	20.9	17.4	18.5	17.3	19.0	18.9	19.9	16.8	18.42	1.240	.265
10	17.3	18.5	20.1	18.2	18.7	17.4	17.5	20.1	18.4	20.5	18.67	1.120	.239
2nd five	....	....	....	....	....	....	....	....	....	....	18.04	.691	.208
11	14.7	16.4	15.0	14.2	14.1	14.7	14.5	14.6	14.7	13.4	14.63	.729	.155
12	16.9	17.2	15.7	16.2	15.2	14.0	17.2	15.7	18.4	17.3	18.45	1.180	.258
13	18.1	16.3	17.7	19.2	17.1	16.7	17.8	15.4	15.4	16.3	17.00	1.160	.247
14	16.3	16.8	16.0	18.1	17.5	16.7	16.8	15.8	16.7	15.9	16.66	.690	.146
15	15.7	16.3	18.8	15.2	15.4	18.5	16.3	18.5	15.4	14.4	16.65	1.550	.330
3rd five	....	....	....	....	....	....	....	....	....	....	16.28	.840	.254
16	16.7	16.1	15.6	16.4	16.3	16.1	17.9	16.8	16.6	16.5	16.50	.570	.121
17	14.3	15.5	15.6	15.2	15.6	14.7	14.9	15.7	14.3	13.7	14.95	1.213	.263
18	19.3	20.2	18.7	18.3	17.8	18.4	18.6	20.3	19.7	19.8	19.11	.800	.175
19	19.4	17.3	18.3	17.2	17.2	17.2	20.6	18.6	17.8	17.5	18.11	1.084	.229
20	16.8	19.8	18.3	18.3	19.6	18.2	19.8	19.0	19.7	18.5	18.80	.919	.196
4th five	....	....	....	....	....	....	....	....	....	....	17.49	1.599	.482
21	20.7	17.8	18.3	18.0	17.2	18.0	18.8	17.0	17.9	18.3	18.20	.969	.202
22	17.8	16.6	17.7	17.7	17.2	17.2	16.9	18.2	17.7	16.2	17.32	.584	.124
23	16.7	16.8	17.2	16.8	17.2	16.4	16.2	17.0	16.9	17.7	16.89	.403	.086
24	19.2	17.9	19.0	18.7	18.8	18.0	17.5	18.8	18.7	19.7	18.63	.600	.130
25	19.7	18.5	20.5	21.5	18.0	17.5	18.2	17.8	19.8	18.8	19.04	1.230	.263
5th five	....	....	....	....	....	....	....	....	....	....	18.01	.798	.241
Summary of twenty-five readings											17.62	1.196	.2031

TABLE II

EFFECT OF PROLONGED MECHANICAL TREATMENT ON BREAD DOUGH

Time of mixing Minutes	Extensibility Square root of volume
4	17.48
8	17.54
16	14.51
24	13.62
32	13.20

EFFECT OF INCREASING THE PROPORTION OF WATER IN THE DOUGH

Dough mixed with the flour used in these studies and containing 60 per cent of the sodium chloride solution had the consistency of normal bread dough. The effect on extensibility of varying this absorption from 59 per cent to 67 per cent was investigated. A dough containing 67 per cent of water was too soft to be handled easily, and the reading on one dough sample varied considerably more than with the stiffer doughs.

As more water was mixed in the doughs, the extensibility increased until the absorption was equivalent to 64 per cent; further increases in the absorption gradually reduced the readings. Chopin reports that with a certain flour which he used the extensibility did not decrease but continued to increase until an absorption of 70 per cent had been reached.

Chopin stated that the tenacity as recorded in millimeters on the water manometer was an indication of the power of the dough to absorb water, as a stiff dough would be more difficult to stretch and would require more pressure. In our experience the amount of oil on the plate and the manner in which the clamp was lifted to allow the water to flow into the measuring tube affected this reading to an appreciable extent, tho it will be observed from the data in Table III that the readings of the tenacity decreased as the proportion of water in the doughs was increased. Since the readings of tenacity were between 90 and 100 millimeters (water manometer) for the doughs giving the highest results, this value in millimeters of water pressure was used as an indication of the proper absorption of the dough. In subsequent tests with this flour an absorption of 63 per cent was used, while with other flours doughs were mixed to give a manometer reading for tenacity between 90 and 100.

TABLE III

EFFECT ON THE EXTENSIBILITY OF INCREASING THE WATER IN A DOUGH

Absorption Per cent	Extensibility	Reading for tenacity Millimeters
59	18.65	125.0
60	18.80	122.0
61	18.90	121.0
62	19.50	117.1
63	19.77	114.7
64	21.00	99.7
65	20.96	94.5
66	20.48	94.5
67	19.66	92.3

EXTENSIBILITY OF FLOUR AND STARCH MIXTURES

The effect of the addition of pure starch to flour is of interest as a method of estimating the importance of the gluten content. Snyder (1901) made baking tests on flours containing starch and found that while the addition of 10 per cent of starch decreased the baking value only slightly, the addition of 20 per cent of starch had a detrimental effect, not only on the volume of the bread, but also on the texture and color. From this work he concluded that the properties of gluten were more important than the quantity of gluten in a flour. More recent work in this Division has indicated that the gas-retaining power of a flour dough is impaired by the addition of starch.

The effect of the addition of starch on elasticity is shown in Table IV. It is evident that increasing the proportion of starch, thus diluting the gluten, diminished the extensibility of doughs made from such mixtures.

TABLE IV

EXTENSIBILITY OF STARCH AND FLOUR MIXTURES

Starch in flour mixture Per cent	Extensibility
0	18.03
10	14.92
20	13.89
30	11.82
40	10.56

EFFECT OF HYDROGEN-ION CONCENTRATION ON DOUGH EXTENSIBILITY

It has hitherto been difficult to measure the effect of varying hydrogen-ion concentration on the properties, including the elasticity of dough. Recent studies of Sharp and Gortner (1923) indicate that glutenin is least hydrated between pH = 6 and pH = 8.5, indicating

that the isoelectric point of this gluten protein is within this range. In an effort to establish the hydrogen-ion concentration of dough possessing the greatest extensibility, doughs were prepared which contained varying quantities of dilute lactic acid, and of dilute sodium hydroxide solutions. The extensibility of these doughs was compared with the control, or untreated dough, prepared with the same flour. The results of these determinations are shown in Table V. In recording the data in this table, the extensibility of the control, or untreated dough, is arbitrarily taken as 100, and the readings on the several treated doughs were calculated, and are reported in terms of the control rather than in the usual Chopin units for extensibility. These data indicate the optimum hydrogen-ion concentration for dough extensibility to be in the region of pH = 6.1. It will also be observed that a dough, the hydrogen-ion concentration of which is outside the range of pH = 5 to pH = 7, has been appreciably lowered in extensibility. Since the diastatic activity and rate of yeast fermentation are apparently greatest on the acid side of pH = 5, the hydrogen-ion concentration at which the dough is most elastic may not be that at which the important enzymes or ferments are most active.

TABLE V

EFFECT ON THE EXTENSIBILITY OF VARYING THE HYDROGEN-ION CONCENTRATION OF DOUGHS

Hydrogen-ion concentration of dough sample	Percentage of original extensibility
7.9	66.7
7.1	78.5
6.7	87.3
6.5	94.6
6.2	95.8
6.1	103.1
5.9	100.5
5.8*	100.0*
5.5	97.0
5.2	93.4
5.1	79.6
4.7	66.7
4.2	48.9
3.5	45.7
3.2	34.5
2.7	34.6
2.5	34.6
2.5*	34.5

*Control of untreated dough.

EFFECT OF CHLORINE TREATMENT ON EXTENSIBILITY

As chlorine bleaching has been shown by Bailey and Johnson (1922) to increase the hydrogen-ion concentration of flours, and as hydrogen-ion concentration has been shown in this work to have a

pronounced effect on the extensibility of flours, it seems probable that treatment with this agent might affect the extensibility of flours.

Samples of flour obtained from the state experimental flour mill had been treated with varying amounts of chlorine gas. They showed a steady increase in hydrogen-ion concentration and a slight decrease in extensibility with an increase in the amount of chlorine used in the treatment. The results are given in Table VI. This method of increasing the acidity has been recommended as a means of improving the baking strength, however, since it may accelerate the activity of certain useful enzymes.

TABLE VI

EFFECT OF CHLORINE TREATMENT OF FLOUR ON EXTENSIBILITY OF THE DOUGH

Chlorine used in treating flour	Hydrogen-ion concentration	Extensibility
Ounces per barrel	pH.	
0.00	6.12	19.03
0.42	6.07	18.85
0.66	6.00	18.59
1.00	5.90	18.34
1.33	5.82	17.76

EFFECT OF FLOUR IMPROVERS ON EXTENSIBILITY

Kohman and his co-workers (1916) stated that calcium sulfate, calcium acid phosphate, and certain ammonium salts were good yeast foods, and recommended adding small quantities to bread dough as a means of improving the bread and saving the yeast. Patterson and Mitchell (1921) recommended the use of calcium peroxide in a dough to increase the capacity of the flour for absorbing water.

The effect of these salts on the strength and elasticity of the dough has not been reported in definite or tangible units because of the lack of a practical method. The change in extensibility due to the addition of these salts in the proportion recommended was studied in order to determine if their beneficial effect was due to their action on the gluten or to the yeast. The results are given in Table VII.

Calcium acid phosphate in every case increased the extensibility of the dough. Phosphoric acid was noticeably detrimental, probably because it increased the hydrogen-ion concentration. Calcium sulfate, calcium peroxide, and magnesium sulfate lowered the extensibility, but with the proportions used the effect was not pronounced.

TABLE VII

EFFECT OF FLOUR IMPROVERS ON DOUGH EXTENSIBILITY

Salt added per cent		Extensibility
Control		17.54
.125	$CaH_4(PO_4)_2$	18.52
.120	$CaSO_4$	16.96
.0025	CaO_2	16.91
.120	$MgSO_4$	16.87
.125	H_3PO_4	14.79

The effect of certain chemical leavening agents and their residual salts upon the properties of dough have been studied by this method. Results of these investigations have already been published by Smith and Bailey (1923).

EFFECT OF FERMENTATION ON EXTENSIBILITY

Since fermentation has been shown to increase the hydrogen-ion concentration of a dough, while in this work an increase in hydrogen-ion concentration was found to be detrimental to the extensibility of a dough, it seems probable that the extensibility would decrease during fermentation. A bread dough was mixed, using the formula suggested by Bailey (1916), large enough for several tests on the extensimeter. A portion was tested immediately after mixing and the remainder was allowed to stand in a fermentation cabinet at 28°C. Portions of this dough were removed, kneaded down, and tested with the extensimeter at one-hour intervals. The results, shown in Table VIII, indicate a gradual decrease in extensibility of the flour as the fermentation proceeds, probably because of an increase in the hydrogen-ion concentration. This would indicate that a very long fermentation may be detrimental to the size and texture of the resulting loaf.

TABLE VIII

CHANGES IN EXTENSIBILITY DURING FERMENTATION

Sample tested	Extensibility
Control dough without yeast and sugar	17.54
Bread dough immediately after mixing	17.38
Dough after 1 hour fermentation	13.36
Dough after 2 hours fermentation	11.72
Dough after 3 hours fermentation	11.43
Dough after 4 hours fermentation	10.62
Dough after 5 hours fermentation	10.76

VALUE OF THE EXTENSIMETER IN INDICATING THE BAKING VALUE OF FLOURS

The primary purpose of the extensimeter is to estimate the baking value of different flours. Altho it can not give any indication of the diastatic action of the flour, the extensibility should be a sufficiently important property that if the method is accurate and diastatic activity

does not vary too widely, the volume of a loaf of bread could be roughly estimated. A series of baking tests had been made of flours from different varieties of wheat grown in Minnesota. Tests for extensibility were made on the doughs prepared from several flours exhibiting varying baking strength and the results are compared with the results of the baking tests in Table IX. Owing to the limited quantity of flour available only one 300-gram sample of dough was used in these tests, making the error greater than if the usual practice of mixing two doughs could have been followed. Instead of comparing the extensibility readings with the increase in specific volume, as Chopin recommended, the results were compared with the readings of the expansimeter described by Bailey (1916). This was done because the expansimeter reading gives a test of the volume that the dough is able to attain under ideal conditions, when not crusted over in the oven. The ratio of the extensimeter reading to the expansimeter reading, shown in column three of Table X, is about 0.211. The relative constancy of the ratio in ten out of twelve comparisons indicates that the extensimeter does afford a basis for estimating the strength or extensibility of a fermented flour dough.

TABLE IX

COMPARISON OF TESTS ON EXTENSIMETER WITH BAKING TESTS

Variety	Grown at	Extensimeter	Expansimeter cc.	Ratio of extensibility to expansion	Loaf volume cc.	Texture score
Mindum	Grand Rapids	11.17	550	.203	1420	92
Pentad	University Farm	12.55	560	.224	1480	91
Crimean	University Farm	13.84	650	.213	1840	100
Turkey	University Farm	13.98	700	.200	1860	100
Kanred	Morris	14.87	700	.212	1700	100
Iowa	University Farm	15.32	750	.204	1860	100
Kota	Grand Rapids	15.33	850	.180	1900	100
Kota	Grand Rapids	16.69	800	.208	1880	100
Kota	Grand Rapids	16.78	750	.224	1900	99
Kota	Grand Rapids	17.97	850	.212	1720	100
Ruby	Grand Rapids	18.47	850	.217	1940	100
Odessa	Morris	19.33	750	.257	1700	100

CONCLUSIONS

Prolonged mechanical treatment or mixing of a dough decreases the extensibility, probably because of an increase in the degree of dispersion of the colloidal particles.

Water added to ordinary bread dough tends to make it more extensible and less tenacious and more easily stretched. After reaching an optimum absorption, the dough becomes less extensible.

Starch mixed with a flour decreases the extensibility of the dough appreciably, indicating that the quantity of gluten in a flour is an important factor in determining flour strength.

Hydrogen-ion concentration is a factor in determining the extensibility of dough. At an approximate pH = 6, the dough is most extensible, and below a pH = 5 or above a pH = 7, the extensibility is greatly lowered.

Chlorine treatment of the flours tends to decrease slightly the elasticity of the dough, probably because it increases the hydrogen-ion concentration, altho it may be of value in increasing the baking value because of accelerated enzyme activity.

Flour improvers are primarily yeast foods and do not necessarily increase the strength of a flour. Calcium acid phosphate tends to increase the extensibility of a dough, phosphoric acid decreases it only slightly in the proportions used.

The Chopin extensimeter readings afford a useful index of the extensibility of a dough and are of value as an indication of the strength or baking value of a flour, giving in one simple and rapid test the result of the several factors that may affect the extensibility.

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